The Impact of Research and Development on Productivity Growth

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Bureau of Labor Statistics
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September 1989

Bulletin 2331

For sale by the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402

Preface

One of the principal functions of the Bureau of Labor Statistics is to inform policymakers on the utilization of the Nation's resources, particularly as this affects the well-being of U.S. workers. Thus, an important part of the Bureau's work is the study of productivity, which is directly related to real income, price stability, employment, and the competitiveness of U.S. goods and services in world markets.

This bulletin presents annual measures of the stock of research and development and its contribution to productivity growth in the nonfarm business economy. The data cover 1948 to 1987. Corresponding data, including revisions, will be made available in the future.

The bulletin is an addition to a series of studies of multifactor productivity growth by the Bureau of Labor Statistics. The initial study, *Trends in Multifactor Productivity, 1948–81* (Bulletin 2178), published in 1983, considered the effects of both capital services and labor inputs on productivity growth. The present bulletin extends the work conducted within this framework to include the stock of research and development.

This program also includes multifactor productivity measures based on gross output and inputs of energy, materials, and purchased services as well as capital and labor services. Such measures have been published for total manufacturing, all two-digit industries within manufacturing, and selected three-digit industries within manufacturing. In addition, the Bureau is developing studies showing the effect of changes in the composition of the labor force and capacity utilization on multifactor productivity growth in the major sectors. Further work on the contribution of research and development to productivity also is anticipated.

The BLS program on the measurement and analysis of multifactor productivity growth is in accord with the recommendations of the Panel to Review Productivity Statistics organized by the National Academy of Sciences and chaired by Professor Albert Rees. The panel's recommendations were presented in *Measurement and Interpretation of Productivity*, published by the National Academy of Sciences in 1979. These recommendations include:

> "The Panel recommends . . . developing and maintaining measures of some of the sources of growth (such as physical capital and work force composition) so that policymakers can have timely and accurate information on at least the more easily measurable sources of productivity change." (p. 15).

Chapter 7 of the panel report, which provides the basis for this recommendation, includes a substantial discussion of the contribution of research and development to productivity growth.

The present study was conducted by the Bureau's Office of Productivity and Technology under the leadership of Jerome A. Mark, Associate Commissioner. Edwin R. Dean, Chief of the Division of Productivity Research, and the late William H. Waldorf, former Chief of the Division, supervised work on this project. Leo Sveikauskas designed and prepared the study and wrote the report. Kent Kunze directly supervised the work.

Robert Evenson, Zvi Griliches, Wallace Huffman, Edwin Mansfield, Frederic Scherer, William Stewart, and Nestor Terleckyj commented on earlier drafts of this manuscript. The Bureau is grateful for the very helpful comments these experts on research and development generously provided. However, none of these scholars is responsible for any errors or imperfections which remain in this report. Responsibility for this work rests solely with the Bureau of Labor Statistics. In addition to the outside readers, Michael Harper of the Bureau provided helpful comments.

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Chapter I. Introduction and Summary of Findings

In view of the widespread interest in U.S. productivity growth and because of its statutory responsibility, the Bureau of Labor Statistics prepares and publishes official measures of productivity growth. For the same reasons, the Bureau has undertaken a sustained program to improve these measures and to make them more useful to the interested public, including other government agencies, policy analysts, researchers, and business and labor leaders. In 1983, as a part of this program, the Bureau published its first measures of multifactor productivity growth (U.S. Department of Labor, 1983). These measures show the growth rate of output per unit of combined and weighted inputs of capital and labor.

The Bureau has prepared a number of other studies of multifactor productivity growth, all within the conceptual and empirical framework established by the initial 1983 study. These studies include development of multifactor productivity measures based on gross output and inputs of energy, materials, and purchased services as well as capital and labor; research projects designed to improve measures of capital inputs; and measures of change in the composition of labor inputs, along with the impact of such changes on multifactor productivity growth. The present study describes work conducted within this program dealing with the contribution that research and development (R&D) makes to U.S. productivity growth. In particular, it provides a detailed account of methods adopted and assumptions made in the preparation of previous Bureau studies of the R&D contribution (Sveikauskas, 1986a; 1986b).

There is ample evidence that R&D is a strong influence on productivity growth. Studies have generally found both that the returns to R&D are extremely high (Griliches, 1973; Scherer, 1982b) and that R&D is the strongest and most consistent influence on observed multifactor productivity growth (Kendrick and Grossman, 1980; Sveikauskas and Sveikauskas, 1982).

Evidence from specific R&D projects provides further support for the notion that research has a substantial impact on output growth. Mansfield et al. (1977) report high private and even higher social returns for a sample of specific research projects. Tewksbury et al. (1980) reach similar conclusions in a subsequent replication. The fact that econometric analyses of the productivity impact of R&D and detailed studies of the return to specific R&D projects both lead to broadly similar results greatly strengthens the confidence that can be placed in the overall conclusion that research has a substantial economic impact. In view of such evidence, it is clear that any attempt to develop a comprehensive understanding of productivity growth must pay considerable attention to research and development.

Economists have frequently approached the contribution of R&D by constructing an R&D capital stock. The procedures used in determining tangible capital stocks are typically also applied to R&D. Annual investments are first deflated into real terms and then transformed into annual stocks through perpetual inventory calculations. Studies of this type generally indicate that R&D contributes about 0.2 or 0.3 percent annually to productivity growth (Griliches, 1980b; Terleckyj, 1982a). However, studies which include the indirect effects of R&D on improved capital or materials quality suggest larger magnitudes may be involved (Scherer, 1982b).

The preferred estimates of the R&D stock prepared in this report indicate that in the private nonfarm business sector, the R&D stock increased at a 7.9-percent annual rate between 1948 and 1973, but slowed to 4.3 percent in 1973-87. Since most research is conducted in manufacturing, growth rates in that sector are similar. Research and development contributed between 0.1 and 0.2 percent annually to multifactor productivity growth in the private nonfarm business sector. However, the slowdown in research growth had an impact of less than 0.1 percent on the 1973-87 productivity slowdown.

In addition to the central series summarized here, a wide variety of alternative R&D stocks based upon alternative assumptions have also been constructed. In most instances, the implied effects of R&D on productivity growth are very similar. However, if R&D does not depreciate, the 1948-87 impact on productivity growth could have been as great as 0.4 percent. Even in this case, however, R&D makes no substantial contribution to the productivity slowdown.

To place these results in perspective, BLS measures of multifactor productivity growth show that capital inputs in the private nonfarm private business sector grew at a 3.5-percent average annual rate in 1948-73 and at a 3.7-percent annual rate in 1973-87. Output per hour increased at a rate of 2.5 percent from 1948 to 1973, reflecting a capital contribution of 0.8 percent and a 1.7-percent contribution from multifactor productivity. In 1973-87, output per hour increased at an average annual rate of 0.9 percent, with capital contributing 0.7 percent and multifactor productivity 0.2 percent. The observed slowdown in the growth of output per hour is therefore largely due to the 1.5-percent decline in multifactor productivity growth; the direct influence of research considered in this bulletin explains very little of the observed slowdown in multifactor productivity growth.[1]

The estimates obtained in the present analysis consider only the direct returns to R&D. However, the present study is only the initial report from a continuing BLS program analyzing the effect of technology on productivity. Subsequent work will analyze the indirect returns to R&D obtained by purchasers further along the chain of production, such as firms which benefit from access to improved capital and materials. In addition, future work will devote considerable attention to the effect of diffusion of technology on productivity. The reader should realize that these indirect effects of research, which are not included in the present bulletin, are extremely important. In fact, they may well account for the larger portion of the total impact of research and development.[2]

Chapter II considers the framework or model within which work on the effect of R&D on productivity has customarily been conducted. Chapter III considers several issues which are central to the calculation of an R&D stock, such as the length of the lag between research expenditures and their effect on productivity, the determination of a deflator for R&D expenditures, and the relative strength of the impact of privately financed or federally financed research on productivity. Chapter IV examines questions of data availability.

Chapter V presents the central empirical series, which rest on specific assumptions concerning each of the items discussed in chapter III, such as the deflator and the influence of federally financed research. This discussion also compares the results of the present study with conclusions from prior work conducted by Griliches, Kendrick, and Denison. Chapter VI constructs several other plausible measures of the research stock, based on alternative assumptions concerning each of the key data issues, and considers their implications for productivity growth. Chapter VI in effect provides a sensitivity analysis illustrating the impact each central assumption has on the implied contribution of R&D to productivity growth. Finally, chapter VII considers several lines of potential future work which could improve measurement of the R&D stock and analysis of its impact.

This bulletin uses a framework similar to that used in most other studies of the impact of R&D on productivity growth. The empirical conclusions are also similar to the results from most other studies, as discussed in chapter V. In addition, the sensitivity analysis conducted in chapter VI shows that a wide variety of plausible alternative assumptions lead to broadly similar conclusions. Nevertheless, it is likely that new and improved methods of analyzing the impact of R&D on productivity growth will emerge in the future. In this context, the estimates presented in this bulletin may eventually turn out to be lower bound estimates of the total impact which R&D and other forms of scientific progress have on productivity growth.

[1]Mark and Waldorf (1983) describe early BLS work on multifactor productivity growth. Dean and Kunze (1988) summarize the evidence for more recent years and also describe further work conducted within the multifactor productivity program.

[2]If the indirect effects of R&D are included, the total effects of research could contribute as much as 0.3 to 0.4 percent to long-term productivity growth. However, because of the substantial time lags involved in diffusion, the indirect impact of trends in research spending on the post-1973 productivity slowdown is likely to be difficult to trace.

Chapter II. Theoretical Framework

This section describes the model or economic framework within which work on the effect of research and development on productivity has generally been conducted. The discussion presented here requires no mathematical symbols. However, appendix A provides a mathematical statement of the central issues and also contains a more thorough and more formal discussion of many important technical issues.

The growth accounting approach to productivity analysis generally starts with the rate of output growth and subtracts the observed contribution of individual inputs from this amount. For example, output growth may be 3 percent in a certain industry; if observed input increases contribute 2 percent to total growth, this implies that multifactor productivity contributes the remaining 1 percent.

The crucial issue in such calculations is determining how much of a contribution the various inputs make to output growth. Experts in productivity growth have typically assumed that the productivity contribution of any input can be measured by its price. For example, if the wage for a particular type of labor is $10 an hour, it is generally assumed that each increased hour of labor of this type contributes $10 worth of increased output. Similarly, if the observed rental price of a dollar of capital is 30 cents, then each additional dollar of capital is assumed to contribute an extra 30 cents worth of output.

However, it is extremely difficult to determine the price of the R&D stock. Most of the returns to R&D appear in data on corporate profits, where they are mixed together with the return to capital. It is therefore difficult to separate the returns to capital and research. Although there is some market for R&D findings, through such procedures as royalties or licensing, there are no reliable and complete figures on these items; in addition, many research findings are never sold. Clearly, many severe problems must be faced in determining the appropriate overall national price of research.

Because of the difficulty of obtaining a reliable measure of the price of the research stock, the present report instead measures the contribution of research to productivity growth directly from studies of the productivity implications of research. Many authors have developed estimates of the productivity contribution or rate of return to R&D.[1]

[1] Studies which have estimated the return to R&D include Griliches (1973), Terleckyj (1974), Griliches (1980a), Sveikauskas (1981), Scherer (1982b), and Griliches and Lichtenberg (1984a).

The literature on the return to R&D has been based on two distinct approaches. One group of studies assumes that the research and development share is a constant proportion of output; another group assumes instead that the productivity contribution, or rate of return, of each unit of research is the same for each firm or each industry within a sample.[2]

Studies of the effect of R&D on productivity growth are now evolving beyond arbitrarily choosing one or another of these two extreme assumptions. More recent work instead uses econometric methods to estimate the extent to which the return to research changes over time.[3] The extent of any change in the return to research is fundamentally an empirical issue. Some work suggests that the return has declined in recent years (Griliches, 1980b). However, it is difficult to determine changes in the rate of return to research over time, largely because disaggregate research data covering a sufficiently long time span are typically not available.

Because information on changes in the rate of return to research over time is important to an understanding of the impact of R&D on productivity, the BLS has conducted further work on this issue. Appendix B summarizes the conclusions from this analysis. The evidence indicates that the return to research did not decline in the 1970's.

The economics literature cited in chapter III also generally finds no decline in the return to research over time. The overall literature and the analysis reported in appendix B consequently both point in the same direction. Therefore, the preferred measures developed in this bulletin assume that the productivity contribution of a unit of research is constant over time. However, chapter VI also considers an alternative series which analyzes the impact on productivity growth if the return per unit of research has declined substantially over time.

Depreciation

Over time, any given asset, such as a physical capital good or an R&D investment, tends to make a less effective contribution to production. Depreciation is an extremely complex concept which involves many issues. In addition, empirical evidence on the depreciation of the

[2] Studies based on the constant R&D share approach include Griliches (1980a; 1980b). Studies which use the constant rate of return approach include Terleckyj (1982a) and Griliches and Lichtenberg (1984b).

[3] Griliches and Lichtenberg, 1984b.

R&D stock is unclear and inconclusive. Some evidence suggests that research and development never depreciates. Other information suggests that the R&D stock is subject to moderate depreciation. Still other evidence indicates that research investments depreciate at an extremely rapid rate. Unfortunately, there has been no definitive study which determines which of these alternatives is generally true.

The present study therefore selects an intermediate rate of depreciation, a geometric decay rate of 0.1, as the rate of depreciation used in the preferred measures. This relatively simple variant assumes that research investments generally depreciate 10 percent in each year of their operation. Further calculations also examine the implications of alternative research stocks based on zero depreciation or a geometric decay rate of 0.2.

The assumed rate of depreciation turns out to have important implications for the effect of R&D on productivity growth. However, at this time it is not possible to determine which assumption about depreciation is most accurate. Further evidence on the appropriate rate of depreciation of the R&D stock would be very helpful.[4]

The social return to research

One further implication of the estimated return to research should also be mentioned here. If research workers and capital are already included in the labor and capital inputs, then the return to R&D will be a social return beyond this private return (Griliches, 1973).

Since typical measures of industry capital and labor input already contain the resources devoted to research, the estimated return in most instances will actually be an externality or social return. (That is, even the estimated direct returns are likely to be social returns.)[5]

Data are not available to examine the magnitude of the bias thereby introduced in U.S. data. However, Cuneo and Mairesse (1984) removed research expenditures from their measures of capital and labor input within data for French firms. Their estimates of the research share then increased from 0.11 to 0.21 or from 0.09 to 0.12 in different samples.[6] These results suggest that correction for such double counting substantially increases the implied research effect.[7]

Alternative approaches

Most studies of R&D have measured output by value added and considered capital and labor as inputs. However, more recent industry studies (Scherer, 1982b) have used a gross output concept, reflecting a gradual trend towards greater reliance on shipments, adjusted for inventory change, as a measure of output throughout the field of economics. Materials are then treated as an additional input. However, essentially the same theoretical structure is retained.

Several theoretical alternatives have been suggested in addition to the variants of the standard procedure. Sveikauskas (1981) suggested a way of discriminating between increased investment in science of the same quality and technical progress in the science sector. This methodology is not considered here.

In another approach, Link (1978) emphasized that the effect of research on productivity was likely to be factor augmenting (affecting either labor or capital predominantly) rather than Hicks neutral (affecting both inputs equally).[8] Finally, Nadiri and Bitros (1980) have suggested that research be treated as an additional factor of production, interacting with other inputs, rather than just as a multiplicative influence on capital and labor. Their results show that R&D influences the observed demand

[4] One important ambiguity affecting the current stock of research is the fact that much research expenditure consists of retrieving, using, and maintaining the previous stock of research rather than adding to new understanding. Similarly, there is much duplication of research in the sense that different projects conducted by different firms overlap. Both of these influences imply that the socially useful stock of research is less than that suggested by the sum of previous R&D expenditures. However, if such circumstances meant that the true research stock were only half that suggested by expenditures data, then the implied accurate rate of return would be twice as high. This example indicates that correction for duplication in research would affect measures of the magnitude of the research stock, but would not alter calculations of the implied contribution of research to productivity growth over time.

[5] For example, in a typical industry, labor input may increase at 4 percent a year and capital input at 6 percent. However, the type of data generally available on industry inputs already includes research inputs. The true growth rate of inputs in this same industry, once research inputs are excluded, may be only 3 percent for labor and 4 percent for capital.

Multifactor productivity growth is determined by subtracting weighted input growth from output growth. If resources devoted to research are subtracted twice, once in capital or labor and again in research, the overall return to research tends to be understated. These matters are discussed more formally in appendix A.

Schankerman (1981) and Cuneo and Mairesse (1984) show that the estimated rate of return does not necessarily have to provide an estimate of the externality effect. However, the empirical work contained in both of these articles supports the externality interpretation.

[6] Specifically, the implied research share is estimated as 0.107 for scientific firms when resources used in research are also contained in the inputs of capital, labor, and materials. The research coefficient increases to 0.206 when resources used in research are excluded from the other inputs. Similarly, for nonscientific firms the research share increases from 0.093 to 0.116 when the labor, capital and materials series are corrected for double counting (Cuneo and Mairesse, 1984, p. 386).

[7] Most studies of the relationship between R&D and productivity growth have been conducted with the industry as the unit of observation. The estimates of the social return, therefore, include benefits which flow to other firms in the industry as the result of one firm's research spending. Similar types of externalities occur when studies use firm data, especially since all the firms in a research-intensive industry tend to have high values of research intensity and to benefit from each other's research (Jaffe, 1986; Bernstein and Nadiri, 1986).

[8] Link (1978, p. 377) lists some of the difficulties involved with his empirical work. One key difficulty is that his approach explicitly requires each industry to be at the same level of technical or entrepreneurial ability. This assumption excludes an important issue at the center of interindustry productivity comparisons. As Link also notes, his estimates of factor augmentation are greater than the residual within each of 45 industries considered.

for both capital and labor, suggesting complementarities between research and these other inputs.[9]

Indirect returns to research

The strongest trend in recent work on R&D has been a greatly increased emphasis on the indirect returns to research, that is, the productivity gains obtained by downstream industries which are able to acquire better quality capital or materials because research-intensive industries have greatly improved their products through heavy research expenditures. The first major evidence supporting this viewpoint is Terleckyj (1974), but Scherer (1982b) is an important further milestone. The central idea of this line of thought is that process innovations fundamentally affect productivity in industries performing R&D, but that the returns to product R&D are obtained by industries further downstream in the production process.

This perspective has become central in recent analysis of the productivity effect of R&D. Estimated indirect returns are very high. However, the channel of effect remains unclear. Terleckyj (1974), who started this line of analysis, reported separate significant effects for research contained in capital and research contained in materials for manufacturing industries; however, the capital effect was very much greater. In nonmanufacturing, research embodied in materials had an effect but, quite surprisingly, research contained in capital did not.

Subsequent work has reported a very diverse picture. Sveikauskas (1981) and the regressions based on the largest sample in Scherer (1982b) report extremely high returns for purchased capital, but none for materials. Other regressions in Scherer's work find significant positive effects for purchase of research through materials.

[9] The growth accounting framework generally does not allow for interactions between inputs very effectively. Nelson (1973) discusses this point. Recent work by Bernstein and Nadiri (1986) and Bernstein (1988) clearly shows that R&D affects the demand for certain inputs more strongly than the demand for other inputs, though the pattern of influence varies among different industries.

More recently, Griliches and Lichtenberg (1984a) divide research used in each industry in Scherer's data into the industry's "own process" research, "own product" research, and imported R&D. They conclude that the influence of R&D embodied in purchases from other sectors is "weak and unstable over time." Finally, in Terleckyj (1984), the research-through-capital variable drops out once an industry's own research is also included.

It is possible that Scherer's results differ from those of Griliches-Lichtenberg because the Griliches-Lichtenberg sample covers only manufacturing industries. Further analysis of this question will therefore probably require some consideration of productivity patterns outside manufacturing, which raises difficult issues of data reliability.

Meanwhile, this study adopts the perspective that the indirect effects of R&D are one obvious method of approaching the diffusion of technical progress. However, since the channel of effect is now unclear and requires substantial further study, since the magnitudes involved are uncertain, and since there is currently no convincing evidence on the associated lags, it does not seem possible to estimate and allow for these indirect effects at present. This report therefore deals only with the direct returns to research.

One qualification involved in this judgment must be understood. Manufacturing industries perform most of the research for the entire economy. Sectors outside manufacturing, such as trade and services, obtain access to most of the research they use indirectly through their purchases of manufactured goods. Consequently, the decision to restrict consideration to only direct research means that the research stock, as calculated, will largely describe research taking place in manufacturing. Chapter V, which includes some tentative estimates of the research stock in the manufacturing and nonmanufacturing sectors, illustrates how strongly research conducted in manufacturing dominates the corresponding figures for the nonfarm business sector.

Chapter III. Prior Evidence on Specific Issues

An extremely wide variety of specific issues must be addressed before the procedures outlined in chapter II can be used to calculate an R&D capital stock and to determine the impact of R&D on productivity growth. The main matters of concern are:

Lags. What is the lag between research expenditures and their effect on productivity growth?

Depreciation. Does the research stock depreciate and, if so, how fast?

The R&D deflator. How should R&D expenditures be deflated?

Basic vs. applied research. Should the research stock include expenditures on both basic and applied research? Should these two components be treated similarly?

Federal Government vs. privately financed research. Should the stock include both federally financed and privately financed research conducted in industry?

Product vs. process research. Should expenditures on new or improved products be included as well as expenditures on new industrial processes?

The impact of the R&D stock on productivity. What contribution does a given increase in the research stock make towards productivity growth?

Changes in the return to research over time. Does the rate of return to a unit of the R&D stock decline over time?

This chapter examines the evidence that the relevant economics literature brings to bear on each of these issues. Each of the eight topics outlined above is considered in turn.[1]

For each of these eight matters, a single basic assumption is selected for use in the primary measures of the research stock and its effect on productivity developed in chapter V. However, for most of these issues, there is no definitive evidence on which specific assumption should be made. Therefore, the discussion in this chapter also considers plausible alternative assumptions; subsequently, chapter VI uses each of these alternatives in constructing other possible variants of the research stock and evaluating their impact on productivity growth. For clarity, the conclusion of each subsection lists the relevant central assumption made in the main series and each alternative considered in chapter VI.

The lag between research and productivity growth

One of the fundamental issues which must be addressed is the lag between research expenditures and their effect on productivity. Much research takes a half year or more to conduct, and also must be put into operation through the preparation and startup of manufacturing and marketing facilities before it has an effect on productivity (Mansfield et al., 1971).

Not very much is yet known about this lag, although there have been several empirical attempts to measure it. One is Evenson's study (1968) using agricultural data, which fits an inverted V lag (in which the impact first increases, then decreases) and comes to the conclusion that the maximum effect occurs after 5 to 8 years, with the total effect dying out after 10 to 16 years. Evenson (1978) provided more recent estimates of the relevant lag structure in agriculture. In industry, Terleckyj (1982a) assumed a 3-year lag for private R&D. Pakes and Schankerman (1984) review evidence on the lag between R&D spending and the beginning of the associated revenue stream, and suggest that typical results take about 2 years. Other studies of the effect of private or publicly financed research suggest considerably greater time lags may be involved (Terleckyj, 1982b; Levy and Terleckyj, 1983).

More generally, Mansfield's broad work on the adoption and diffusion of innovation contributes to an understanding of the lag in the effect of research. Lags of 10, 15, or 20 years in the adoption of innovations appear to be fairly frequent. Consequently, one should expect that the full effect of R&D appears only with a very considerable lag. In particular, the lags associated with the purchase of research-intensive capital and materials

[1] A further issue is whether foreign research investment should be included. Clearly, as foreign technological levels have approached U.S. levels and as American multinational corporations have conducted more research abroad, foreign R&D has become more relevant to U.S. firms. However, the relative weight to be attached to a unit of foreign research and how this may have changed over time are unclear.

from other sectors can be expected to be especially lengthy.

Considerable work has been done on the related topic of the lag between research performance and observed corporate profits. Branch (1974) defined research as patent applications (corrected for patent office delays) and found the maximum effects to be between 2 and 3 years. However, because there is a lag between research expenditures and patent applications (Pakes and Griliches (1984b) estimate this is 1.6 years), the true lag between research expenditures and profits is probably greater. Ravenscraft and Scherer (1982) reported that the lag between research expenditures and maximum profits was 4 to 6 years. This seems a more plausible estimate.

The research-profit lag clearly does not coincide with the research-productivity lag.[2] Nevertheless, in the typical scheme of events, innovations provide new profits as a product is introduced and sales increase; later on, as imitation proceeds, the innovator's sales growth slows down and profits decline. In this interpretation, imitation brings about a profit decline at a time when productivity is still increasing because new producers are still adopting the innovation.

Basic research is defined as research directed purely at the creation of new knowledge, whereas applied research or development is work conducted with a commercial aim. Clearly, basic research conducted within scientific disciplines such as physics, biology, or mathematics affects production in a much more long-range way than applied work. No specific information is available on the lag between the performance of basic research and the time at which these expenditures have an effect on productivity. However, the lags involved are likely to be far greater than those associated with applied research.[3]

In the measures prepared in chapter V, we select a lag between research performance and initial effect on productivity. This lag clearly is less than the lag between research performance and maximum effect, which most of the studies cited above consider.

The preferred measures presented in chapter V are based on initial lags of 2 years for applied research and 5 years for basic research in industry. The 2-year span is comparable to that used in Terleckyj's (1982a) calculations of industrial R&D stocks, which are based upon 2- or 3-year lags. The 5-year span for basic research is selected as a substantially longer time period.

The R&D stocks presented in chapter V make specific assumptions concerning the lag between research expenditures and productivity growth. These assumptions are consistent with the lags utilized in previous work. Furthermore, the sensitivity analysis conducted in chapter VI shows that changes in the lag have relatively little effect on the implied contribution of R&D to productivity growth. In addition, since the raw data on annual research expenditures and the corresponding deflator are reported in chapter V, interested investigators will be able to examine the impact of alternative assumptions.

Because there are many different influences on productivity, including the business cycle and a host of other factors, it would be unwise to attempt to determine the lag from time-series data on research and productivity in only a single context, such as in the nonfarm business sector or in manufacturing. Detailed micro data, including many observations in many different contexts, will be necessary before any reliable lag patterns can be established. Therefore, this report makes no attempt to determine the research stock-productivity effect lag from major sector data.

Summary: A 2-year lag between research expenditures and productivity is used as the preferred measure for applied research, and a 5-year lag is used for basic research. For applied research, lags of 1 and 3 years are considered as alternatives.

Depreciation

Selection of the rate of depreciation of the research capital stock involves major conceptual and empirical problems. Over time, investments in R&D depreciate in the sense that they are no longer able to contribute as much to production. For most assets, the depreciation which occurs over time reflects elements of both physical decay and obsolescence. For R&D, physical decay is probably minimal, but obsolescence, which occurs because methods based upon recent research typically displace older techniques which rely upon research conducted years ago, or because investments in older research are no longer relevant under current circumstances, is likely to be substantial. As an example of research which is no longer relevant, much research on energy or petrochemicals conducted prior to 1973 is probably no longer able to make a relevant contribution to production now that oil prices are higher than $10 dollars per barrel.

On an empirical level, further important issues arise in determining an accurate version of depreciation. These involve both selecting the appropriate research lifetime and choosing the correct pattern (such as geometric,

[2] The research-profit and research-productivity lags differ because research leads to higher productivity and greater profits, but the profits tend to erode while the productivity remains. Therefore, the research-profit lag in a sense provides lower bound estimates of the research-productivity lag.

[3] Some case-study information on the lag between the conception of an innovation and its first realization is contained in Battelle Columbus Laboratories (1973) and other references contained in that study. The average lag from initial conception reported there is 19 years. Lags from the time in which the initial basic science is conducted are apt to be longer.

Levin, Cohen, and Mowery (1985) describe very useful data which may eventually be able to provide a fuller understanding of the relationship between the extent to which different industries rely on the various fields of science and their observed productivity growth.

hyperbolic, or one-hoss-shay) and rate of depreciation.[4] Unfortunately, no work on research depreciation as comprehensive as the highly detailed Hulten-Wykoff (1981) study of physical capital depreciation (one of the studies that the Bureau used in its work on the capital stock) has ever been conducted. Therefore, there is no conclusive or even reliable evidence to guide the selection of the appropriate shape and speed of the depreciation of R&D investment. In the absence of any decisive empirical evidence, it is useful to examine how various empirical studies have treated the depreciation of the R&D stock.

Griliches (1980a) approaches the depreciation problem by assuming zero percent, 10 percent, and 20 percent (presumably geometric rates) as alternative annual rates of depreciation. Research capital stocks are then calculated under each assumption. Terleckyj (1982a) assumes no research depreciation under one variant and, alternatively, lives of 5 years for own-research and 7 years for research obtained indirectly from other industries. Terleckyj uses straight-line depreciation in these calculations. These two variants are intended to be extreme values, alternatively assuming very slow and very fast research depreciation.[5]

Terleckyj (1982a) pointed out that the most reasonable results occurred in his productivity regressions when research depreciation was set at zero. Griliches and Lichtenberg (1984b) report further evidence which supports the no-depreciation assumption. On the other hand, Pakes and Schankerman (1984) find that investments in research depreciate quite rapidly (in the neighborhood of 20 or 30 percent) within individual firms.

One further observation supports the assumption of zero depreciation. A fixed annual research investment, such as funding a 10-person laboratory, probably represents a constant annual amount of real research investment using typical R&D deflators. Because annual real research investment is constant, if depreciation is positive, eventually the implied research stock contributed by this laboratory stops increasing and becomes constant. This implies that eventually the laboratory makes no further contribution to productivity growth. In reality, however, a laboratory of fixed size is likely to continue making new and useful contributions to productivity growth, in part because the cumulative nature of science ensures that later scientific work is likely to represent an improvement over prior work using comparable resources (Sveikauskas, 1981).

On the other hand, it is undeniably true that with the passage of time some portion of research is typically no longer able to contribute to output and productivity. On balance, in view of these conflicting considerations, a 10-percent geometric depreciation rate is adopted as the primary assumption for the research stock measures. In addition, depreciation rates of zero percent and 20 percent geometric decay are selected as alternatives.[6]

As in the case of lags, it is difficult to determine depreciation parameters from industry or major sector data, because reliable data are available for only a few sectors. Detailed micro evidence will eventually be necessary to address the lag and depreciation problems, as proved to be the situation in the case of capital. The Griliches data base prepared for a study financed by the National Science Foundation included data on research by 490 firms in 1970 and 800 or more in subsequent years. Such richly detailed evidence, which includes some firms in which research spending is expanding very rapidly and others in which it is stable, will be useful in addressing the interrelated questions of depreciation and lags.[7]

Summary: Ten percent geometric depreciation is used for applied research in the central measure; zero depreciation and 20 percent geometric depreciation are used as alternatives. Basic research is assumed not to depreciate.

The R&D deflator

The R&D deflator is one of the major problems to be

[4] These terms refer to alternative mathematical functions describing the time path of depreciation. The geometric decay version assumes a constant rate of depreciation each year. The hyperbolic function permits different rates of decay to occur in different years, including the possibility of slow decay in earlier years and more rapid decay in later years. The one-hoss-shay pattern assumes that, like the legendary carriage, there is no decay at all; the asset in question retains its full productivity until it eventually collapses and is totally unusable at the end of its lifetime. BLS, after careful consideration of available evidence, adopted the hyperbolic function for its work on capital stocks. For a formal statement of the hyperbolic function, see U.S. Department of Labor (1983), appendix C.

[5] King and Fullerton (1984, p. 29) consider the conditions under which straight-line depreciation provides a present value equivalent to exponential (geometric) depreciation. They show that straight-line depreciation over L years is approximately equivalent to geometric depreciation at the rate of 2/L. Therefore, the Terleckyj assumption of asset lives of 5 or 7 years is approximately equivalent to geometric rates of depreciation of 29 to 40 percent.

[6] Geometric decay is adopted in the present study because this is a particularly simple form and has frequently been adopted in R&D studies. The data required to test the validity of several alternative forms of decay do not exist. On the other hand, much better data exist on the price of depreciating capital assets. The BLS study of capital stocks reviewed evidence on this matter and concluded that hyperbolic decay most closely approximated the actual decay of capital assets (U.S. Department of Labor, 1983). The Bureau therefore will continue to use hyperbolic decay functions in its work on capital assets.

[7] It may be possible to use portions of the Griliches firm data to examine the depreciation and lag issues. However, such analysis will not be easy. The reader should be aware that a detailed study of 133 firms (Griliches and Mairesse, 1984) which was specifically planned to examine the effects of various ways of defining and measuring physical and R&D capital (p. 347) was not able to establish definitive estimates of the magnitude of depreciation and lag effects (pp. 372-373). In addition, depreciation at the firm level is not necessarily the same as at the industry level. Under certain circumstances, research may no longer contribute to a firm's productivity growth, but may still be contributing to industry productivity growth through other firms. Appendix A provides further information on the depreciation issue.

considered in developing measures of the research capital stock. The National Science Foundation currently utilizes the GNP deflator to deflate research expenditures into real terms. However, it is widely recognized that this procedure is highly questionable. In particular, empirical evidence indicates that the price of scientific inputs has generally increased more rapidly than the GNP deflator (Mansfield, Romeo, and Switzer, 1983). Therefore, use of the GNP deflator may introduce considerable bias.

Griliches (1979) refers to several attempts to construct a deflator for specifically technological expenditures, but also points out the serious limitations of these attempts. Since the Griliches article was published, two further noteworthy studies have addressed the deflator issue.

First is the study by Goldberg (1979). He created a deflator based on substantial input detail for 14 manufacturing industries. The indexes cover years from 1956 to 1975. Many of the data series underlying these estimates, for example the compensation for Engineer V and Draftsman II, are produced by the Bureau of Labor Statistics.

Goldberg's work leads to two main conclusions. First, R&D prices increased faster than the GNP deflator from 1956 to 1967, but in 1967-75 increases in the two price series were roughly similar, and in fact the GNP deflator went up slightly more. For example, in chemicals, the R&D deflator increased from 70 in 1956 to 100 in 1967 and 158 in 1975. In contrast, the GNP deflator increased from 80 in 1956 to 100 in 1967 and 160 in 1975. Second, Goldberg found that R&D prices went up roughly the same amount in all industries.

Counter to the grain of previous conclusions, the Goldberg evidence is supportive of the use of the GNP deflator to deflate R&D. First, evidence on the rate of price inflation is mixed, with R&D costs increasing substantially faster than the GNP deflator in one period and slightly less in another. In addition, Goldberg's data are substantially less reliable for 1956-62, so part of the 1956-67 discrepancy can be discounted. In the period with better data, from 1962 to 1975, the R&D price index increased 73 percent whereas the GNP deflator increased 71 percent, almost the same. Second, Goldberg's results show that R&D prices increased at roughly the same rate in all industries, which supports the notion of using a common R&D deflator, such as the GNP deflator, for all individual industries.

Work conducted by Mansfield (1982) and Mansfield, Romeo, and Switzer (1983) represents a further important advance towards a more accurate measure of the R&D deflator. The Mansfield data show that R&D costs increased considerably faster than the GNP deflator for 1969-79. Overall, the GNP deflator increased by 88 percent from 1969 to 1979, whereas the R&D cost increase was 98 percent. Such an increase in the deflator means that if the Mansfield cost estimates are used to deflate R&D instead of the GNP deflator, most of the apparent increase in R&D spending disappears for the Mansfield sample of industries in the 1970's. Mansfield, Romeo, and Switzer also cite an OECD study which showed that in all ten countries considered (Japan, Canada, and eight European countries), the R&D deflator increased more rapidly than the GDP (gross domestic product) deflator. Finally, Mansfield's results indicate that in 1969-79 R&D costs increased at different rates in various industries, from 83 percent in electrical equipment to 122 percent in chemicals and petroleum to 148 percent in fabricated metal products. More recent work on the research deflator in 12 industries between 1969 and 1983 suggests similar patterns; in particular, increases in the price of R&D diverge widely between industries (Mansfield, 1985).

The Mansfield results differ from Goldberg's in several respects. First, they suggest a sharper divergence between R&D costs and the GNP deflator in the late 1960's and early 1970's. Second, they suggest considerably wider variability in industry trends than the Goldberg data. Mansfield's results are probably more soundly based than Goldberg's because they rely on actual cost data collected from firms conducting R&D, which is preferable to assuming that published price trends on certain items used in R&D can provide a good indication of research cost trends.

In summary, the weight of the evidence indicates that R&D costs increase more rapidly than the GNP deflator. This difference should certainly be accounted for in any measure of the R&D stock.

Griliches (1984), following earlier work by Jaffe, suggests that a weighted index of 49 percent of hourly compensation and 51 percent of the implicit deflator, both in the nonfinancial corporations sector, approximates the 1969-79 Mansfield results fairly well. Appendix D of the present study describes the calculation of a 1921-87 deflator based on this Jaffe-Griliches concept. This study adopts these measures as the central deflator for R&D expenditures. However, the GNP deflator presently used by the National Science Foundation is used in an alternative set of calculations in chapter VI.

As mentioned above, the Jaffe-Griliches deflator is based on data for nonfinancial corporations. However, because actual information on prices and costs in this sector is only available from 1958 onwards, considerable work has been required to estimate nonfinancial corporations' prices and costs between 1921 and 1957. As appendix D describes, 1947-57 nonfinancial corporations' prices and costs were estimated on the basis of the 1958-87 relationship between price and cost indexes in the nonfinancial corporations sector and their counterparts in nonfarm business. Subsequently, the 1947-87 relationship between the Jaffe-Griliches deflator and the GNP deflator was used to estimate 1921-46 values of the Jaffe-Griliches deflator.

The estimates of the Jaffe-Griliches deflator constructed in this way probably provide a reasonable measure of long-term trends in the national price of R&D. However, Mansfield (1985) has shown that, although the Jaffe-Griliches deflator described actual research costs from 1969 to 1979 well, this measure somewhat underestimated the actual 1979-83 increase in the price of research.

Summary: The Jaffe-Griliches deflator based on nonfinancial corporations data is used in the preferred measure. The GNP deflator is used in an alternative measure.

Basic vs. applied research

The main issue to be addressed here is whether investments in both basic and applied research should be included in the research stock and, if so, how they should be combined. The first work on these questions was conducted by Mansfield (1980). The central evidence is that basic research has a strong influence on productivity growth; in fact, in regressions which include both variables, the basic research variable typically dominates applied research as an influence on productivity. Of course, since basic research represents only about 3 percent of industrial research expenditures, this does not mean that only basic research is important. More likely, the presence of basic research permits applied research to be more deeply and soundly based and therefore results in higher overall returns. More recently, Griliches (1986) also reported that basic research has considerably stronger effects on productivity growth than applied research on the basis of an analysis of firm data.

In view of the evidence, basic research expenditures should clearly be included in the R&D stocks. On the other hand, the mechanisms and connections underlying the high returns Mansfield and Griliches report for basic research have not yet been definitively established. The stocks reported here therefore assume the rate of return is the same for both basic and applied research. On the issues of lags and depreciation, basic research clearly requires a longer time lag until it takes effect than applied research does, and is less likely to suffer from depreciation. Therefore, separate accounts are kept for basic and applied research, so that lags and depreciation can be treated differently within each category.

Finally, the total overall research stock is obtained by adding the basic and applied research stocks. More complex methods of aggregation, such as the Tornquist method of aggregation frequently used in preparing BLS measures of capital input, typically weight each subcategory of factor input by its price. However, in the central calculations reported in this bulletin, basic and applied research stocks are each assumed to have the same price (the return of 30 percent), so Tornquist aggregation leads to the same result as the addition of the basic plus applied research stocks.[8]

Summary: Basic and applied research stocks are calculated separately and then added for the preferred measure; no alternative is considered.

Federal Government vs. privately financed research

The main question to be addressed here is whether the research stock appropriate to productivity growth should contain federally financed research conducted in industry or only privately financed expenditures.

The central evidence on this topic, which is due to Leonard (1971), is that federally financed research conducted in industry has no effect or very little effect on private sector productivity. Some studies have occasionally found a partial and incomplete positive impact of government-sponsored research, but the far more dominant pattern is that federally financed expenditures have no discernible effect on productivity growth (Terleckyj, 1982a).

The evidence that government-financed research has little effect basically arises from interindustry productivity regressions. However, several studies conducted at the firm level have found that federally financed research does have a positive impact. Griliches (1979; 1980a) shows that, within data on a large number of firms, total R&D explains productivity trends better (in the sense of a lower standard error of estimate and larger coefficient of determination) than privately financed research does. Griliches (1986) also reports, using firm data for the 1970's, that privately financed research has a larger coefficient than federally financed research, but that the latter still has a positive effect.

Some evidence indicates that at the aggregate level federally financed R&D also has a direct effect on private sector productivity (Levy and Terleckyj, 1983). However, the effect is not large (0.065 in one estimate as opposed to a 0.258 return to private research investment). In addition, this conclusion is not very robust, since it does not occur in several alternative specifications.

[8] Assume that the aggregation of basic research stocks and applied research stocks is given by

$$\alpha_b \dot{B}/B + \alpha_a \dot{A}/A \qquad \text{(a)}$$

in which α_b and α_a are shares of the total research share, B is the basic research stock, and A is the applied research stock. Then, (a) is equivalent to:

$$p_b B/(p_a A + p_b B)\, \dot{B}/B + p_a A/(p_a A + p_b B)\, \dot{A}/A \qquad \text{(b)}$$

in which p_b and p_a are the prices for basic and applied research. Since $p_a = p_b$ in the present application, expression (b) becomes:

$$B/(A + B)\, \dot{B}/B + A/(A + B)\, \dot{A}/A \qquad \text{(c)}$$

which is also:

$$\dot{B}/(A + B) + \dot{A}/(A + B) = (\dot{B} + \dot{A})/(A + B) \qquad \text{(d)}$$

an expression which is equivalent to the rate of growth of the total research stock, as obtained by simply adding the basic and applied research stock.

Because the industry results are based on a larger number of studies, and because the Bureau plans to develop industry measures of the R&D stock consistent with the national measures presented here, we have chosen to emphasize the evidence from the industry analysis and include only privately financed research in the preferred R&D stocks. However, an alternative measure is also constructed which includes 20 percent of federally financed research expenditures conducted in industry; this weight is approximately consistent with the results reported by Griliches. The sensitivity analysis conducted in chapter VI shows that the main conclusions are not greatly altered if one-fifth of the federally financed R&D conducted in industry is assumed to influence productivity growth.

Studies which have attempted to see if government research stimulates private research generally find some effect but not an extremely strong one (Goldberg, 1979). Levy and Terleckyj (1983) summarize evidence on this issue. Mansfield (1984) also emphasizes the idea that federally financed research makes its contribution fundamentally by stimulating privately funded research. More recently, Lichtenberg (1986) considered the possibility that federally financed research stimulated private research spending through the competition for Federal research contracts. His results suggested that this mechanism accounted for almost half of the increase in privately financed research spending from 1979 to 1984; of course, federally financed military research expenditures grew at an unusually rapid rate over this period.

The relatively slight productivity contribution from government-funded research is somewhat surprising in view of the important role that government-financed research has played in such prominent areas as the computer, jet aircraft, modern airplanes, and radar. Nevertheless, the notion that government research has relatively little direct civilian spillover is fairly widely accepted. Experience with government-financed research programs in the 1970's provides further support for such a viewpoint (Piekarz, 1983).[9]

Summary: The preferred measure contains only research financed by industry. The alternative measure gives federally financed research conducted in industry a weight of 20 cents on the dollar.

Product vs. process research

Any attempt to create research stocks must face the possibility that research conducted on new processes (new methods of production) affects productivity directly, whereas research on new products shows up less strongly or in other sectors as part of the diffusion of technology. For example, a rearrangement of machinery to reduce production costs is a process innovation, whereas a new toaster is a product innovation. If these different types of research affect production in different ways, perhaps separate process and product research stocks should be prepared.[10]

Several studies have examined this issue. The first is the Link (1982) analysis of firm productivity growth over a rather brief time period, 1974 to 1978. In this sample, total research did not significantly affect productivity growth. However, when product and process R&D were split, the coefficient of new product R&D remained insignificant, but new process R&D was significant.[11] Comparable results occurred when dummies allowed for broad overall industry differences in research intensity.

The second study which addresses the product/process issue is Scherer (1982b). Research and development is divided into R&D provided to other users as new products and R&D consumed by an industry, which includes both its own new process spending and the purchase of research embodied in purchases from other sectors. The data base was constructed through a highly detailed study of patents.[12] It was expected that research on new products would not affect an industry's observed productivity growth, but that research used in an industry would have a positive impact. Contrary to these expectations, however, Scherer found (in the broadest sample he considered) that research on new products sometimes did have a positive effect on productivity growth. The coefficient for research used in an industry was, as expected, positive. However, when research used in an industry was divided into one's own process R&D and research conducted elsewhere, as in the case of the purchase of new machinery, the coefficient for own process R&D was not significant at conventional levels, although the coefficient approached significance in two of the three regressions reported.[13]

In a third study, Terleckyj (1982a) reported that research conducted in an industry had an effect on the industry's own productivity only when the research stock was limited to process R&D.

The fourth study is a more disaggregate application of Scherer's data on the product and process R&D conducted in each industry (Griliches and Lichtenberg, 1984a). This

[9] More generally, Nelson (1982) and Gray, Solomon, and Hetzner (1986) have conducted broad reviews of the evidence concerning the effectiveness of Federal and State and local government attempts to aid in the development of new technology.

[10] As Griliches (1979) indicates, whether R&D conducted in an industry shows up in the producing industry or the consuming industry depends on whether the relevant price indexes capture the quality change which occurs in the research-performing industry's output. This problem is particularly severe in the case of the dynamic technological change which often occurs in industries with a high research/sales ratio.

[11] The coefficient for total research was 0.046 with a t ratio of 1.31. The coefficient for new product R&D was 0.014 with a t ratio of 0.50, and that for new process R&D was 0.219 with a t ratio of 1.73.

[12] Scherer (1982a) describes these data development procedures in detail.

[13] These t ratios were 1.60 and 1.49.

study showed that own process and own product research each had significant positive effects in two of the three time periods considered. These results, therefore, suggest that new product research does affect productivity in the originating industry. On the other hand, the return to process research averaged 58 percent over the three time periods, whereas the return to new product research was only 18 percent.

The different studies on the relative importance of product versus process research do not reach any consistent conclusion. However, since the Griliches-Lichtenberg study covered the most comprehensive sample, all manufacturing using rather detailed data, their results are the most convincing. Product research probably has a positive, though a lesser, return. Further empirical work on this topic would certainly be useful.

It is important to note that Griliches and Lichtenberg generally find a positive effect for an industry's new product research. This conclusion differs from the theoretical perspective adopted by Link and Scherer, who expect that an industry's product research will not contribute directly to its own productivity and that all its research impact will be indirect. Since most research is conducted on new products (Scherer, 1984), a measure of the direct first-round impact of research would not be very useful if new product research had no such effect. In contrast, the Griliches-Lichtenberg result implies that new product research should be included in a study of the direct effect of R&D on productivity.

On balance, the evidence cited above shows that it would be useful to distinguish between product and process R&D and perhaps allow for a relatively greater direct rate of return to process research. However, because of the difficulties involved in obtaining reliable data on these different components of research, the present work does not make this distinction.

The major potential source of information on the product and process components of research is the *Survey of Business Plans for Research and Development* conducted by the Economics Department of the McGraw-Hill Company. From 1974 to 1983, McGraw-Hill asked respondents to report what percentage of their total research spending is on new products, new processes, and the improvement of existing products.[14] The percentage distributions for total manufacturing in selected years are as follows:

	1974	*1978*	*1980*	*1983*
New products	36	34	37	43
New processes	14	24	19	19
Improvement of existing products	50	42	44	38

McGraw-Hill also reports similar data on the percentage of new process spending for each two-digit manufacturing industry, but these data are on the basis of which industry each company is classified in, rather than by product field. These detailed data also are available only from 1974. In addition, the May 1985 and May 1986 versions of the McGraw-Hill survey, which report information for 1984 and 1985, no longer contain data on the proportions of research investment contained within each of these categories for each industry. Since the data are available for only a few years, they are not sufficient to justify any attempt to create separate stocks of product and process research.

Finally, the most important development in this area is the data on total national product and process R&D published by the National Science Foundation. However, since this series began only in 1979, these data are also, at present, not very helpful in constructing R&D stocks.

Summary: The central measure contains both product and process research. No alternative is considered.

The impact of the R&D stock on productivity

This section examines empirical evidence on the impact of R&D on productivity growth, particularly the productivity benefit directly obtained by the industry or firm undertaking research investment. The discussion summarizes econometric evidence on the productivity impact of research in 13 studies. (The next subsection considers the related issue of whether the effectiveness of R&D has declined over time.) Many of the studies discussed here call the impact which research has on productivity growth the rate of return; however, the present study sometimes calls this same concept the productivity impact to avoid confusion with the particular sense in which the term rate of return or internal rate of return has typically been used in the capital service price literature. Appendix A discusses these issues of terminology somewhat more extensively.

In the earliest published study of the contribution of R&D to productivity growth in manufacturing (Griliches, 1973), the productivity impact of research (the coefficient of research intensity in a regression explaining productivity growth) was found to be 40 percent within 85 industries in manufacturing. An alternative version, which did not rely on questionable book-value measures of the capital stock, suggested a 32-percent impact.

Terleckyj (1974) concludes that the direct impact is approximately 30 percent in manufacturing. However, there was no evidence of a positive effect outside manufacturing.

The Mansfield et al. (1977) study is fundamentally different from the other studies mentioned here since it calculated the actual rate of return to a number of individual R&D projects rather than econometrically estimating a rate of return from firm or industry data. Because the Mansfield estimates are calculated directly, they are not subject to a variety of potential biases which

[14] Prior to 1974, the McGraw-Hill survey asked whether the majority of a respondent's R&D was conducted on product or process research, rather than for a specific percentage breakdown.

might affect the econometric evidence and therefore are a very useful supplement to the econometric studies. The Mansfield study reported that the median private rate of return was 25 percent and the median social rate of return was 56 percent for a sample of 17 innovations.

Griliches (1980a) reports a direct impact of 30 to 40 percent in most industries, except for some sectors in which federally financed research was especially important.

Griliches (1980b) shows that the effect of research was fairly high in 1959-77 if no other variables were included, but lower when other influences were included. He also found that the 1969-77 influence was much lower than the 1959-68 estimate.

Mansfield (1980) showed that the measured rate of return was typically considerably greater for basic research than for applied research within both industry and firm data. Within firm data, the rate of return to all research, including both basic and applied research, was 28 percent.

Sveikauskas (1981) reported a direct impact in the neighborhood of 20 to 30 percent, which, however, declined to 10 to 20 percent when indirect research (R&D embodied in capital or materials purchased from other sectors) was also included.

Terleckyj (1982a) reported an insignificant direct impact for research in the 1970's, which became significantly positive when attention was limited to the industry's own process research.

Scherer (1982b) also found a significant positive direct influence before the 1970's but insignificant effects in the 1970's. The most comprehensive of his detailed industry regressions for the 1970's showed a coefficient of 0.29 for exported R&D (research eventually used by other sectors) and 0.74 for imported and own process R&D.[15] However, other samples showed insignificant effects for R&D exported through product sales.

Griliches and Lichtenberg (1984a) reported significant positive coefficients for an industry's own process plus product research. The average value of this coefficient was about 0.24 for the three periods considered. In other work, they found a 0.09 to 0.33 return to research investment (Griliches and Lichtenberg, 1984b). Clark and Griliches (1984) found research returns in the neighborhood of 18 to 20 percent in a study of divisional data of large firms. Finally, the rate-of-return estimates in Griliches (1986), though they are rather difficult to compare with prior estimates because they include a premium for basic research and company-financed research, suggest overall returns in the range of 30 to 60 percent.

Table 1 summarizes some of the main characteristics of each of these studies, such as whether they deal with industry or firm data, or use a gross output or value added definition of output.

On the basis of the evidence summarized here, this study adopts the assumption that the direct impact of research is 30 percent. Since most of the evidence cited above refers to industry data, this estimate reflects both private returns to firms and the externalities accruing to firms within the same industry. There are studies which

[15] These regressions analyzed labor productivity growth in terms of the growth in the capital-labor ratio and R&D intensity in a sample of 81 industries, using 1973-78 labor productivity data from the Bureau of Labor Statistics. Scherer constructed the R&D variables on the basis of a highly detailed analysis of the Federal Trade Commission *Line of Business* data.

Table 1. Central characteristics of the main studies of the contribution of research and development to productivity

Study	Types of data	Years of R&D data	Output definition	Indirect effects
Griliches (1973)	Industries	One	Value added	No
Terleckyj (1974)	Industries	One	Value added	Yes
Mansfield et al. (1977)	Specific R&D projects	Many	Firm increases in revenue	Yes, social returns
Griliches (1980a)	Firms	Many	Value added; gross output	No
Griliches (1980b)	Industries	Many	Gross output	No
Mansfield (1980)	Industries and firms	One	Value added	For industries
Sveikauskas (1981)	Industries	One	Gross output	Yes
Terleckyj (1982a)	Industries	Many	Value added	Yes
Scherer (1982b)	Industries	One	Gross output	Yes
Griliches-Lichtenberg (1984a)	Industries	One	Gross output	Yes
Griliches-Lichtenberg (1984b)	Industries	Many	Gross output	No
Clark-Griliches (1984)	Divisions of firms	Many	Gross output	No
Griliches (1986)	Firms	Many	Value added; gross output	No

show lesser effects, particularly in the 1970's, and many studies which show stronger influences. However, the 30-percent estimate is fairly well supported. Appendix A provides further information on many other issues relevant to understanding the impact of research and development on productivity growth.

Summary: The central measures assumes a real return of 30 percent. No alternative rate is considered.

Changes in the return to research over time

A few years ago, there was a general impression that the productivity impact of research had declined radically in the 1970's, contributing to the productivity slowdown (Griliches, 1980b). Now, it seems clear that the impact of research did not decline in the 1970's (Griliches and Lichtenberg, 1984b; Clark and Griliches, 1984; Griliches, 1986). The problem appears to be that earlier conclusions were based on two-digit productivity data, which cover too small a number of industries and aggregate dissimilar production processes.

Ravenscraft and Scherer (1982) and Scherer (1983) report evidence from profits data that the return to R&D was abnormally low in cross-sections for 1970, 1971, and 1975, but recovered in the late 1970's. Such results suggest that, although there was a positive return to R&D in the 1970's, the overall return during this period may have been smaller than usual. Consistent with such a perspective, the early 1970's was also a period in which increases in private R&D spending were relatively slight. For example, constant-dollar privately financed industrial R&D expenditures increased from $26.19 billion in 1969 to only $26.26 billion in 1972 and $27.54 billion in 1975.

Kendrick (1979) estimated the effect of research on productivity growth assuming returns of 50 percent for 1948-66, 45 percent in 1966-73, and 40 percent in 1973-78. These figures were chosen because they reflected observed trends in the return to capital. Not enough information was then available to judge the realism of such assumed reductions in the productivity contribution of research. Similarly, the available cross-section production function estimates of the return to research were not precise or detailed enough to show how the return varied over different short time periods.

More recently, however, considerable work has been done on changes in the impact of research over time. Griliches and Lichtenberg (1984b) studied data for manufacturing. To reduce cyclical effects, they divided the data into time periods, over which they averaged. For example, the first period studied was 1959-63 to 1964-68; the last, 1969-73 to 1974-76. In addition, Clark and Griliches (1984) studied data from the PIMS project, a Harvard Business School project which contains data for divisions of major corporations; they tested for the possibility of a change in the R&D coefficient over time in the 1970's. Both studies found the impact of R&D held up rather well in the 1970's. Another study by Griliches and Lichtenberg (1984a) also pointed in the same direction. In addition, Griliches (1986) found no decline in the return to research in an analysis of firm data from 1967 to 1977. All the studies mentioned in this paragraph are based on much more detailed data than prior work on changes in the rate of return over time.

Further work on changes in the rate of return to research over time was conducted for this study. The evidence is reported in appendix B of this bulletin and essentially supports the studies cited above in concluding that the return to research held up fairly well in the 1970's.

In contrast, Mansfield (1979) suggested, on the basis of an analysis of firm data and on the judgment of R&D managers, that the rate of return to research may have declined in the 1970's. This conclusion is based on less comprehensive data than in the later studies.

The preponderance of the detailed evidence so far shows no reduction in the return to research over time. The preferred measure therefore assumes no decline in the rate of return. However, an alternative measure permits the impact of research to decline.

Summary: The preferred measure assumes the productivity impact of research is constant over time. The alternative measure assumes a decline from 30 percent in 1967 to 16.67 percent in 1987, a decline of 0.67 percent per year.

Chapter IV. Data Availability

Data on 1953-87 research expenditures in the nonfarm business economy are obtainable from National Science Foundation publications.[1] The annual data are available from the yearly volumes of *Research and Development in Industry*.[2] In addition, the National Science Foundation has published summaries of the relevant time-series data in *National Patterns of Science and Technology Resources*.

However, it is difficult to obtain data for sectors other than the nonfarm business economy. In particular, it is difficult to partition data for the nonfarm business sector into its manufacturing and nonmanufacturing components. Similarly, substantial problems arise in determining a research series for agriculture.

Before proceeding to a discussion of these specific data issues, however, it is useful to provide some background information on the data available on R&D expenditures. The available data contain two different types of information. One type classifies annual R&D expenditures by industry of performance. Each company is classified into a specific industry, and all research performed by the firm is attributed to that industry. For a major firm such as the General Electric Corporation, the firm would presumably be classified in electrical equipment manufactures. Consequently, all research conducted, including research on chemicals and information systems, would be allocated to the electrical equipment industry and not to each industrial field. In addition, the year-to-year totals are occasionally subject to major breaks when an important company is reclassified from one industry to another, although the National Science Foundation has generally attempted to smooth the series to ensure that such shifts are less sharp.

Because of these limitations, most R&D stock studies have used the second type of industry classification, which refers to R&D conducted by product field. These product field data refer only to applied research and are therefore often referred to alternatively as the applied product field data. Basic research is not included. In this framework, all research is classified into industry categories by the type of product field involved. For example, textiles research is counted as textiles regardless of whether it is conducted by textile or chemical firms. One serious problem with the detailed industry product field data is that the reliability of the published data is questionable in some cases (Griliches and Lichtenberg, 1984b). However, the data can be appropriately adjusted, as discussed in appendix B of Griliches-Lichtenberg (1984b).

Both the industry of performance data, built up from company sources, and the applied product field data are published according to Standard Industrial Classification (SIC) codes. However, in the applied product field data, research is listed for 28 broad product fields, since information is published for some groups of three-digit industries, as well as for many two-digit industries. This represents slightly more detail than available for industry of performance. In addition, a cross-classification matrix showing research by industry and product field also exists, though this is not available for each year and includes many cells for which data are not separately shown.

The industry of performance and applied product field data are both obtained from a survey that is conducted annually for the National Science Foundation by the Bureau of the Census. This survey covers all firms with research spending greater than $1 million, and contains a sample of smaller firms.

The R&D expenditures data cover all labor cost and materials purchases for research in a specific year. However, current research resources spent on capital, such as the structures or equipment used in industrial research, are measured by the implied depreciation of these assets, rather than by observed expenditures for such purposes.

The firms typically obtain data for this questionnaire from their accounting records. Although the NSF forms contain detailed guidelines, individual firms probably exercise considerable latitude in assigning individual research expenditures to specific applied fields and in

[1] One matter of terminology must be clarified here. The BLS multifactor productivity measures for major sectors refer to the private nonfarm business economy, which excludes government enterprises, such as publicly owned water or electric companies and the U.S. Postal Service. The measures of output used in this bulletin also consistently refer to the private nonfarm business economy. The research stock is similarly based on research expenditures in industry and does not include government enterprises. The R&D measures are therefore also consistent with the output definition adopted.

For purposes of brevity, some portions of the text occasionally refer to the nonfarm business sector. However, throughout this bulletin, the term nonfarm business sector always refers to the private nonfarm business sector.

[2] The title of this publication has changed occasionally over the years. For example, from 1962 to 1965 the corresponding report was called *Basic Research, Applied Research and Development in Industry*. The 1958 and 1959 reports were called *Funds for Research and Development in Industry*.

determining whether specific projects constitute basic research, applied research, or development.

We now return to the main theme of this section, which is whether acceptable measures of the research stock can be created for the major sectors. One important problem is dividing the available information on research expenditures into its manufacturing and nonmanufacturing components. Since this issue requires detailed and extensive consideration, it is discussed at length in appendix C. The main conclusion of appendix C is that there is at present no fully reliable way to separate research expenditures and stocks into their manufacturing and nonmanufacturing components. Therefore, this bulletin emphasizes R&D stocks calculated at the nonfarm business level, which includes both the manufacturing and nonmanufacturing sectors.

Agriculture

Originally, it was hoped to include the agricultural sector in this study, so that the data could provide information for the total private business economy as well as for the nonfarm business sector. However, construction of a relevant R&D stock for agriculture presents serious problems. Evenson (1978) demonstrated that R&D expenditures have a substantial impact on productivity in agriculture. However, most of the research which affects agricultural productivity is financed by the Federal or State governments, such as research financed by the U.S. Department of Agriculture or by various land-grant universities, or is research conducted by private firms in manufacturing, such as work on insecticides or fertilizers. Both the government and private work are conducted primarily outside the agriculture sector and therefore provide only indirect benefits to farmers. The present bulletin considers only direct returns to research and therefore does not address these indirect returns, which are of crucial importance in agriculture.

The only component of research relevant to agriculture which appropriately belongs in this bulletin is private research conducted directly in the agricultural sector. Ruttan (1982) summarizes the very sparse information available on private research conducted directly within agriculture. As Ruttan indicates, data are available for only a few years, generally in the late 1970's. This information is clearly insufficient to support construction of time-series estimates of a stock based on private research spending in agriculture.

Ruttan presents an overview of the industrial research expenditures which influence productivity in agriculture and agricultural processing. Summary figures for 1978 for private expenditures on this research are as follows, in millions of dollars:

Total	$1,392-$1,497
Plant breeding	55-150
Pesticides	290
Plant nutrients	3
Animal breeding	49
Animal health (mostly veterinary drugs)	99
Animal feed and feed ingredients	30
Farm equipment and machinery	225
Farm product transport equipment	40
Food processing machinery	85
Food processing	350
Tobacco manufacturing	40-50
Natural fiber processing	10
Packaging materials	116

These estimates show that most private research funds which affect agriculture are spent in manufacturing rather than in agriculture. For example, the pesticides, animal health drug, and farm equipment categories and all the last six items clearly take place in manufacturing. Only the plant breeding, animal breeding, animal feed and feed ingredients, and perhaps the plant nutrients categories fall into agriculture. In 1978, these items together accounted for only about $134-$229 million of the total of $1,392-$1,497 million private expenditures on research which affected the agricultural system.

Another potential source of information on private research conducted directly in agriculture is the data compiled by the Federal Trade Commission *Line of Business* survey. These data show that private research expenditures in agriculture were $5.7 million in 1974 and $6.7 million in 1976. These sums are far smaller than the expenditures of more than $1 billion suggested by Ruttan. This discrepancy partially occurs because the FTC data are based on totals for large corporations in manufacturing, whereas much of the Ruttan data were gathered from agricultural trade associations, which presumably have more access to information on expenditures by smaller economic units or by nonmanufacturing companies. In addition, the Ruttan figures include data on research conducted in industrial lines of business eventually used in agriculture.

Finally, Scherer (1982a) used an adjusted version of the *Line of Business* data to estimate that company-financed research conducted in agriculture was $128.1 million in 1974. However, as Scherer indicates, his nonmanufacturing estimates are probably subject to a considerable range of error.[3]

In the stocks constructed for the nonfarm business sector in chapter V, all private R&D expenditures reported by the National Science Foundation are attributed to the nonfarm business sector. No attempt is made to subtract expenditures occurring in the farm sector since data on this topic are so sparse.

Detailed industry data

For greater industry detail, beyond the two-digit level, the only source of comprehensive data relates to 1973-77. This is the Federal Trade Commission (FTC) line of business survey, as reported in the FTC annual *Line of*

[3] There is an additional way in which federally financed research may have had an important influence on production. Basic research in biochemistry and medicine, such as that conducted at the National Institutes of Health, has surely affected medicine, hospitals, and the drug industry. No study appears to have examined this topic, particularly the effect on measured productivity.

Business report. The data have not been extended to subsequent years and consequently are not very useful for analysis of the long-term effects of research. However, the *Line of Business* report is a highly useful source of information on research expenditures within a large number of industries.

BLS periodically collects data on R&D employment in manufacturing and other sectors. Surveys of manufacturing were conducted in 1971, 1976, 1980, and 1983. This source of data, which provides considerable industry detail, gives some indication of major interindustry differences in research intensity. However, research expenditures clearly provide a more comprehensive picture of research intensity than research employment does, and so it is preferable to use an estimate of expenditures.

The NSF is the only source of reliable data on research spending over time in detailed industries. Terleckyj (1982a) has developed data on R&D in each product field from 1958 to 1977 from the NSF data. These figures are subdivided into research financed privately and research financed by the Federal Government. The Terleckyj industry series does not include any expenditures from the residual product field, so total manufacturing spending is greater than the sum of these industry values.[4]

R&D expenditures prior to 1953

Research and Development in Industry includes annual company-based data on R&D by industry of performance from 1957. In addition, two earlier surveys covering the 1953-56 period were conducted by the BLS. However, these two data sets are not regarded as comparable. The NSF has presented comparable national totals for 1953-56 (*Funds for Research and Development in Industry, 1958*). The product field data start in 1957; no earlier data exist. In addition, the company data distinguish between private and publicly financed funds from 1958 on. However, the applied field data are divided into private and public components only after 1967.[5]

The NSF data starting in 1953 clearly must be the core of any series for major sectors. However, the NSF publishes no data for prior years. The main information on prior years is the aggregate data contained in Terleckyj (1963).[6] Fortunately, the Terleckyj study and the NSF data use the same central concepts. The Terleckyj data begin in 1921. Research and development conducted as early as the 1920's proved to have little impact for most of the postwar research stock estimates prepared for this bulletin. However, if it is assumed that there is no depreciation, all prior investment is included in the research stock. Therefore, in this instance all data are cumulated from 1921. In evaluating this particular series, the reader should be aware that choice of any specific initial year is inherently arbitrary and depends on data availability.

Data on federally funded research conducted in industry prior to 1953 are obtained from the Blank and Stigler study (1957), which in turn is based on Department of Defense data. Federally funded projects are calculated as research performed by industry less funds raised by industry. This procedure indicates $90 million of Federal funding occurred in 1941, the first year for which data are available. Amounts of $60 million in 1940, $30 million in 1939, and zero prior to 1939 were assumed.

Overview: R&D relevant to productivity growth

An overview may now be provided of the portions of national R&D included in the measures presented in this bulletin. Data for 1977 are used for illustration.

In 1977, total national R&D expenditures were $42.8 billion. These were distributed as follows (in billions):

Conducted in the Federal Government	$6.0
Federally financed	6.0
Conducted in industry	29.8
Federally financed	10.5
Industry financed	19.3
Conducted at universities and colleges	4.1
Federally financed	2.7
Industry financed	.1
University and college financed	.9
Other	.3
Conducted at federally funded R&D centers (Example: Oak Ridge National Laboratory)	1.4
Conducted at other nonprofit institutions	1.5
Federally financed	1.0
Industry financed	.1
Other nonprofit	.4

The R&D stock used in this study includes the following elements of the 1977 expenditures listed above:

Industry research financed by industry	$19.3
University and college research financed by industry	.1
Other nonprofit research financed by industry	.1

[4] As explained in appendix C, the residual product field consists of applied research expenditures which are not assigned to any specific product field. Many of these items would most appropriately be assigned to specific product fields in manufacturing.

[5] Despite problems of comparability with subsequent data, one source, BLS Bulletin 1148, *Scientific Research and Development in American Industry* (Bureau of Labor Statistics, 1953), may eventually be useful in developing industry estimates for early years. This source includes estimates of R&D expenditures, including estimates of industry expenditures and even separate estimates of government and private expenditures in each industry in 1951. This source could potentially be helpful in developing rough estimates of total and private research expenditures for manufacturing and specific industries prior to 1958. However, the National Science Foundation R&D report for 1957 emphasized that these 1951 data and subsequent estimates for 1953-54 and 1956 often differ widely from NSF data at the industry level.

[6] The central question is whether the Terleckyj data are sufficiently reliable, even though they have never been adopted in official NSF publications. To gain information on this question, BLS consulted with William Stewart, then head of the National Science Foundation R&D Economic Studies Section. The NSF never adopted data prior to 1953 because data for earlier years were never required. However, if they needed information for prior years, they would probably adopt the Terleckyj series. Given this favorable opinion of the Terleckyj data, we proceeded to adopt them for years prior to 1953 and the corresponding NSF data for subsequent years.

This represents a conservative measure of the relevant R&D, limited to research conducted in industry financed by private funds, which has been clearly demonstrated to affect productivity, and also research in colleges and universities and nonprofit institutions financed by industry, which is assumed to affect productivity equivalently.

No attempt is made to select an arbitrary percentage of some of the other categories of research (such as those chosen by Griliches (1973)) because the relevant percentage chosen for each category of research would be difficult to justify.

On the basis of the evidence presented in chapter III, no Federal funds are included in the index of R&D expenditures relevant to private sector productivity growth. However, Federal funds used in industry are included in the data base prepared for this study and are used in one of the alternative measures analyzed in chapter VI.

One important element of Federal research expenditures which is not included in the data base is spending on agricultural research. The NSF series on Federal budget authority for R&D in agriculture (about $550 million in 1977) is not included because such expenditures do not take place in the nonfarm business sector.

Finally, the product versus process distinction is also relevant here, but, as discussed above, because of data limitations, it is not possible to create separate stocks for these two categories at the present time.

Chapter V. Empirical Results

This chapter describes the preferred measures of the R&D stock and their impact on productivity growth. It also compares these results with the conclusions reached in earlier studies.

As noted in chapter III, the central series is based on a 2-year lag between applied research expenditures and their impact on productivity and a 5-year lag for basic research, 10 percent geometric depreciation for applied research, the Jaffe-Griliches deflator, simple addition of basic plus applied research, a research expenditure series confined to privately financed research, and no change over time in the impact of research on productivity.

It is important that the reader realize that evidence on many of these issues is mixed, and a plausible case can easily be developed for various alternative assumptions. Chapter VI examines how a variety of alternative assumptions concerning these topics affect conclusions concerning the impact of R&D on productivity growth. The assumed rate of depreciation is the only alternative assumption which turns out to have important implications for understanding the role of R&D.

Because at present it is not feasible to divide the available data into reliable measures of research expenditures in the manufacturing and nonmanufacturing sectors, this chapter concentrates primarily on R&D stocks in the nonfarm business sector as a whole. However, for illustrative purposes, tentative estimates of research stocks for the manufacturing and nonmanufacturing sectors are also reported.

Nonfarm business sector

Table 2 shows the central information on annual expenditures on R&D. All data refer to the nonfarm business sector. The preferred measures are based on total R&D expenditures financed by industry, as reported in the first column. Table 2 also presents information on federally financed research expenditures conducted in industry, since a portion of these expenditures is included in one of the alternative series examined in chapter VI.

Most industry-financed R&D is of course conducted in industry. Industry-financed research by universities and colleges and nonprofit institutions is also included in the main research expenditures series. The sum of all these expenditures constitutes a conservative lower bound estimate of the expenditures relevant to productivity growth, in the sense that government-financed expenditures are not included.

Table 3 presents similar data for basic research expenditures in the nonfarm business sector. Applied R&D expenditures can be determined from total R&D (table 2) less basic research expenditures (table 3).

Table 4 shows the information available on R&D expenditures in the nonmanufacturing sector, as obtained from the company data of the National Science Foundation. Prior to 1958, nonmanufacturing research investment was estimated as a fixed proportion of applied research and basic research investment in the nonfarm business sector. The proportions used were based on the 1958 data. Estimates were developed through this procedure for all previous years. Table 4 contains detailed data sources for years after 1958.

Table 5 presents estimates of total private R&D expenditures in years prior to 1953. Fortunately, Terleckyj (1982b) independently selected the same concept and definition of relevant research expenditures adopted in this study, so the data listed in table 5 are consistent with the privately financed research expenditures reported in table 2. Similar data on annual R&D expenditures are presented in Terleckyj (1984). No information is available on the basic and applied components of privately financed research conducted prior to 1953, so the 1953 proportions (92.7 percent for applied research and 7.3 percent for basic research) are arbitrarily assumed to hold for each prior year.

Table 6 lists corresponding information on federally financed research conducted in industry prior to 1953. Data are from Blank and Stigler (1957). These expenditures are divided between basic and applied research in the same proportions as in 1953; 0.014 of federally financed research is assigned to basic research and the remaining 0.986 to applied research.

Table 7 shows the Jaffe-Griliches deflator used to deflate all forms of research investment. All research investment is converted to 1982 dollars using these deflators. Table 8 gives the GNP deflator, which is used in chapter VI to determine an alternative research stock. Table 9 lists research expenditures in the food processing applied research product field, in order to illustrate the nature of information available at this level of industry detail. Table 10 lists annual investment in applied and basic research, each in 1982 dollars.

Table 11 shows the preferred estimates of the R&D stock. Separate figures are presented for applied and basic research. The preferred measure of the applied research stock is based on a 2-year lag and 0.1 geometric depreciation, in light of the discussion in chapter III. The stock of basic research assumes a 5-year lag and zero depreciation. In 1987, the total R&D stock, calculated as the sum of the basic research stock and the applied research stock, was $361.25 billion in 1982 dollars.[1]

Table 12 shows the long-term growth rates of the research stock and its applied and basic components. Since, as table 11 indicates, the basic research stock constitutes less than 15 percent of the total research stock, applied research dominates the growth of the total research stock. Growth in basic research tends to be slightly greater than the growth of applied research essentially because basic research stocks are calculated with zero depreciation; if the applied stocks were calculated without depreciation, they would have increased at a 7.4-percent rate over the long-term (1948-87) period, which would mean the applied research stock would have grown faster than the basic research stock.

Table 12 also examines the growth in the research stock within the 1948-73 and 1973-87 periods. The research stock grew at a 7.9-percent rate from 1948 to 1973, but slowed to 4.3 percent, about 54 percent of the earlier growth rate, between 1973 and 1987.[2]

Table 13 lists several other important characteristics of the R&D stock. Column 1 lists the annual rate of depreciation of the total research stock. The annual rate of depreciation is essentially constant over time.[3] Column 2 lists the annual growth of the R&D stock. The growth rate varies over the business cycle and over time. The key feature is that the growth of the research stock slowed substantially, from 7 to 9 percent per year in the 1950's and 1960's to 4 or 5 percent in the 1970's and 1980's. Column 3 indicates the real return to each unit of the research stock in each year, which is assumed to be constant at 30 percent. Column 4 shows the implied R&D share of total real income, based on this 30-percent assumption, in the nonfarm business sector. The research share increased steadily from slightly more than 1 percent in 1949 to about 3.5 percent in 1987.

[1] To gain some perspective on this magnitude, in 1987 the total capital stock in nonfarm business—the sum of the equipment, structures, rental residential housing, inventories, and land stocks—was $7,433 billion in 1982 dollars. Therefore, the R&D stock was approximately one-twentieth the size of the total capital stock.

[2] As mentioned in Norsworthy, Harper, and Kunze (1979), some economists believe the productivity slowdown began in the late 1960's rather than in 1973. The growth of the research stock slowed from 8.1 percent in 1948-67 to 5.2 percent in 1967-87; from this perspective, research maintained 64 percent of its previous long-term growth rate. Consequently, the data suggest that the growth of the research stock slowed down more rapidly in the post-1973 period.

[3] The constant rate of depreciation is not surprising since 0.1 geometric depreciation is assumed throughout the period, which indicates that 10 percent of the research stock is lost every year. The ratio in table 14 is less than 0.10 because basic research is assumed not to depreciate. The value of 0.087 in table 13 implies that 87 percent of the research stock is applied research, which depreciates at a 0.1 geometric rate.

Of course, one major question is what implication these research stock figures have for understanding the productivity slowdown. Table 14 expands the analysis to consider the effects which the growth of the research stock and the research shares listed in table 13 have on productivity growth. Table 14 lists the annual contribution of R&D in the nonfarm business sector, as determined through the growth accounting methodology described in chapter II.[4]

These data show that fluctuations in research have had a noticeable, although minor, effect on productivity growth in the nonfarm business sector since 1948. The productivity impact of R&D increased from 0.10 percent in 1950 to about 0.17 percent in the 1960's. This impact declined to as low as 0.11 percent in the late 1970's. In the early 1980's, the productivity contribution of R&D increased again and returned to its mid-1960's values. Nevertheless, the magnitudes involved are not very great.

Table 15 shows the average annual contribution of R&D to productivity growth for specific time periods. For the overall 1948-87 period, R&D contributed 0.15 percent to productivity growth. For 1948-73, R&D contributed 0.15 percent and for 1973-87, 0.14 percent. If the contribution to the productivity slowdown is measured solely within these periods, R&D made no appreciable contribution to the slowdown.

For the sake of completeness, table 16 presents the output data used in calculating each year's research share. The table shows constant-dollar (1982 dollars) output in the nonfarm business sector for each year between 1948 and 1987. Together with the real R&D stock presented in table 11, this material provides the information required to determine the relevant research share for each pair of years.[5]

The estimated shares reported in table 13 show clearly that, if the return to research is anywhere near constant, the assumption of a constant research share cannot be supported. It is possible that the productivity contribution of a unit of research declined gradually over time, which would cause the research share to grow more slowly than table 13 suggests. However, even if the implied price of a unit of research declined by as much as one-half over

[4] The growth accounting methodology determines the contribution which any factor input makes to productivity growth by multiplying its rate of growth by its factor share. Appendix A provides a detailed discussion of growth accounting and describes the procedures through which the productivity contribution of R&D is calculated.

[5] Note that conclusions concerning the effect of R&D on productivity depend in an important way on the assumption that the productivity contribution of a unit of research capital, rather than the research share, is constant. If the research share were instead assumed constant, the slowdown in the growth of the research stock documented in table 13 would have a somewhat greater impact on productivity growth. For example, given a research share of 0.02, which is roughly plausible for the nonfarm business sector, the growth rates in table 12 would then suggest that R&D contributed 0.16 percent to productivity growth in 1948-73 and 0.09 percent in 1973-87, thereby contributing 0.1 percent to the productivity slowdown.

the time period considered, table 13 shows that the assumption of a constant research share would still be subject to serious question. In addition, the empirical studies summarized in chapter III found no evidence that the return to research has declined over time; further empirical work on this topic conducted at BLS, which is reported in appendix B, also found no evidence of a decline.

Manufacturing and nonmanufacturing

Table 17 provides estimates of the research stock in the manufacturing and nonmanufacturing sectors, with research investments in the two sectors determined from the nonmanufacturing company data discussed in chapter IV. The calculations in table 17 are intended to illustrate the general orders of magnitude involved and may considerably understate the true amount of research which occurs outside manufacturing. Nevertheless, research stocks are certainly far greater in manufacturing than in the nonmanufacturing sector.

As expected, the direct influence of R&D on productivity growth is greatest in manufacturing, where most research is concentrated. In manufacturing, direct R&D contributed 0.49 percent to 1948-87 multifactor productivity growth (table 18). There is no evidence that research played any substantial role in the productivity slowdown in manufacturing; the estimated contribution declined only from 0.50 percent in 1948-73 to 0.49 percent in 1973-87.

On the other hand, the direct research effect is almost nil in nonmanufacturing, where most research is purchased indirectly, as embodied in goods purchased from manufacturing. The direct effect on the productivity slowdown is inevitably extremely slight, given the small magnitudes involved. A more conclusive split of research investments between manufacturing and nonmanufacturing might alter the levels of the stocks considerably, but the pattern of the results would remain unaltered.

Comparison with previous measures

This section compares the empirical results obtained above with prior studies of the role of R&D in productivity growth and of the influence of R&D in the productivity slowdown.

Griliches (1973) conducted a widely cited study of the effect of R&D. This analysis included some components of publicly financed reseach and some portions of university-funded and Federal intramural research. This concept of relevant research is therefore broader than that considered in the present report, which includes only privately financed research. However, Griliches also assumed that only some percentage of research spending in some of these broader categories directly affected productivity growth. In addition, the Griliches study did not consider lags.

Griliches concluded that R&D contributed perhaps 0.3 percent to measured productivity growth in 1966 and about 0.2 percent in 1970. Griliches regarded these estimates as within the upper range of plausible results.

In contrast, the present study suggests that the productivity impact of R&D was 0.15 percent in 1966 and 0.18 percent in 1970. These magnitudes are somewhat lower than the Griliches estimates, but not unreasonably so, since the Griliches analysis assumes a considerably broader range of research expenditures is relevant.

In another study, Griliches (1980a) examined the potential effect of a slowdown in R&D using an estimate of a constant research share of 0.06 in manufacturing. This study suggested the slowdown in R&D might have reduced productivity growth in manufacturing by 0.14 percent. The present study shows no such substantial effect on the productivity slowdown, largely because the procedures adopted here assume a constant return to research instead of a constant research share, as discussed in chapter II.

Kendrick (1981, 1984) has consistently found that research contributes a considerably larger amount to productivity growth. Kendrick (1981) estimated that R&D contributed 0.85 percent to productivity growth in the U.S. domestic business economy in 1948-66, 0.75 percent in 1966-73, and 0.60 percent in 1973-78. The magnitudes involved, and the contribution to the productivity slowdown, are far greater than those reported in this bulletin. Kendrick (1984) reported that the effect of research on productivity growth declined from 1.2 percent in 1948-73 to 0.7 percent in 1973-81.

The Kendrick numbers are larger than other estimates for several reasons. First, much or all of government research expenditures are included as relevant expenditures; as Mansfield points out in his comments on Kendrick (1981) and as Denison (1979) observes, this is likely to overstate the true impact of the research stock. Second, Kendrick uses higher estimates of the rate of return than other studies, which presumably is intended to reflect the impact of the substantial indirect effects of R&D. An extension of the present work to include indirect effects as well as the direct effects would presumably bring the present estimates somewhat closer to Kendrick's results. Third, Kendrick (1984) assumes that "the many small technological improvements made in shops and offices tend to follow the major developments produced by formal R&D programs." Little is known about this issue. However, since most R&D is conducted by large corporations in manufacturing, small improvements contributed by small firms outside manufacturing, such as the shops and offices Kendrick mentions, may be driven by quite different forces.

Denison (1979) considers various alternative estimates of the impact of R&D, and essentially agrees with the Griliches estimate of 0.3 percent as a maximum effect in the total economy. In addition, he considers a range between 0.0 and 0.1 percent as plausible contributions to the productivity slowdown. This range of magnitudes is consistent with the central conclusions reached in the present bulletin.

Scherer (1983) estimated that the slowdown in R&D may have reduced productivity growth by 0.2 or 0.3 percent a year; his discussion implies R&D may have contributed as much as 0.4 percent a year to the productivity slowdown. These high estimates occur because Scherer uses estimates of the total return to R&D which include very large indirect effects. Total annual returns to R&D are estimated to be between 70 and 100 percent or even higher. If the 30-percent return used in the present report were used instead, the estimated contribution to the productivity slowdown from Scherer's approach would be only 0.1 percent a year. This substantial difference shows the importance of addressing the complex issue of the indirect returns to research.

Table 2. Total research and development expenditures,[1] nonfarm business, current dollars, 1953-87

(In millions)

Year	Industry-financed R&D: Total	Industry-financed R&D: Conducted in industry	Industry-financed R&D: Conducted in universities and colleges	Industry-financed R&D: Conducted in nonprofit institutions	Federally financed R&D conducted in industry
1953	$2,245	$2,200	$19	$26	$1,430
1954	2,373	2,320	22	31	1,750
1955	2,520	2,460	25	35	2,180
1956	3,343	3,277	29	37	3,328
1957	3,467	3,396	34	37	4,335
1958	3,707	3,630	39	38	4,759
1959	4,064	3,983	39	42	5,635
1960	4,516	4,428	40	48	6,081
1961	4,757	4,668	40	49	6,240
1962	5,123	5,029	40	54	6,435
1963	5,456	5,360	41	55	7,270
1964	5,888	5,792	41	55	7,720
1965	6,548	6,445	41	62	7,740
1966	7,328	7,216	42	70	8,332
1967	8,142	8,020	48	74	8,365
1968	9,005	8,869	55	81	8,560
1969	10,010	9,857	60	93	8,451
1970	10,444	10,288	61	95	7,779
1971	10,822	10,654	70	98	7,666
1972	11,710	11,535	74	101	8,017
1973	13,293	13,104	84	105	8,145
1974	14,878	14,667	96	115	8,220
1975	15,820	15,582	113	125	8,605
1976	17,694	17,436	123	135	9,561
1977	19,629	19,340	139	150	10,485
1978	22,450	22,115	170	165	11,189
1979	26,081	25,708	193	180	12,518
1980	30,911	30,476	235	200	14,029
1981	35,944	35,428	291	225	16,382
1982	40,096	39,512	334	250	18,483
1983	43,515	42,861	379	275	20,542
1984	49,066	48,308	458	300	23,162
1985	52,597	51,724	538	335	26,484
1986	55,549	54,574	600	375	28,988
1987	58,570	57,500	670	400	31,700

[1]Expenditures for basic plus applied research.

Sources: National Science Foundation, *National Patterns of Science and Technology Resources,1953-1977*, table B-1; *National Patterns of Science and Technology Resources, 1987*, table B-1.

Table 3. Basic research expenditures, nonfarm business, current dollars, 1953-87

(In millions)

Year	Industry-financed R&D: Total	Industry-financed R&D: Conducted in industry	Industry-financed R&D: Conducted in universities and colleges	Industry-financed R&D: Conducted in nonprofit institutions	Federally financed R&D conducted in industry
1953	$153	$132	$12	$9	$19
1954	168	143	14	11	23
1955	191	162	16	13	27
1956	249	216	18	15	37
1957	266	230	21	15	41
1958	292	252	24	16	43
1959	290	248	24	18	72
1960	342	297	24	21	79
1961	361	314	25	22	81
1962	394	345	25	24	143
1963	425	375	25	25	147
1964	434	384	25	25	165
1965	461	406	26	29	186
1966	510	451	27	32	173
1967	492	427	31	34	202
1968	535	462	36	37	180
1969	540	458	39	43	160
1970	528	444	40	44	158
1971	547	456	46	45	134
1972	563	463	53	47	130
1973	605	499	57	49	132
1974	651	536	61	54	163
1975	705	573	72	60	157
1976	769	634	71	64	185
1977	850	701	79	70	210
1978	964	785	99	80	250
1979	1092	893	114	85	265
1980	1267	1,035	137	95	290
1981	1588	1,313	170	105	301
1982	1813	1,500	198	115	380
1983	2045	1,692	228	125	460
1984	2418	2,004	279	135	471
1985	2647	2,152	345	150	476
1986	2815	2,270	375	170	524
1987	2970	2,400	390	180	600

Sources: National Science Foundation, *National Patterns of Science and Technology Resources, 1953–1977*, table B-1; *National Patterns of Science and Technology Resources, 1987*, table B-1.

Table 4. Total research and development expenditures, nonmanufacturing, current dollars, 1958-87

(In millions)

Year	Federally financed		Industry financed	
	Total	Basic research	Total	Basic research
1958	$62	$10	$55	$4
1959	92	14	48	4
1960	110	17	58	5
1961	124	20	70	6
1962	152	24	83	7
1963	190	21	85	6
1964	229	27	90	5
1965	268	22	116	8
1966	367	28	130	11
1967	387	44	172	9
1968	431	43	172	10
1969	448	40	207	8
1970	480	27	225	8
1971	452	24	252	7
1972	$ 431	$19	$ 277	$9
1973	416	19	299	9
1974	463	14	305	12
1975	310	14	425	11
1976	375	21	471	8
1977	417	37	541	7
1978	527	42	702	8
1979	681	47	859	10
1980	779	54	1,037	12
1981	858	59	1,048	12
1982	904	62	1,101	13
1983	1,022	71	1,167	14
1984	1,215	84	1,370	16
1985	1,485	102	1,366	16
1986	1,626	112	1,441	17
1987	1,778	123	1,518	18

Source: National Science Foundation, *Research and Development in Industry*, various, as listed below.

Data prior to 1958 (not shown) are determined from the 1958 ratios of the percentage of applied research investment occurring in nonmanufacturing (1.493 percent) and the corresponding percentage of basic research (1.379 percent) occurring in nonmanufacturing.

For basic research, estimates for 1958-61 use 1962 estimates of the ratio of basic to total expenditures: 0.1576 for Federal, 0.0794 for industry financed.

The annual volumes of *Research and Development in Industry* provide information on the total research and basic research conducted by firms classified in nonmanufacturing. More recent versions of these same data, such as that published in *National Patterns of Science and Technology Resources: 1987*, tables B-26 and B-27, and *Research and Development in Industry, 1979*, tables B-6 and B-12, provide updated information on total expenditures for 1974-85 and 1963-73. These revised figures have been used for the total expenditures series. (Tables 3, 7, and 9 of *Research and Development in Industry, 1970*, provide the available information for 1958 to 1962.)

However, the annual figures on basic research spending by nonmanufacturing companies have not been revised. Therefore, the proportion of basic research to total research suggested by the original data for each year is applied to the updated total expenditures series to obtain estimates of basic research conducted in each year by these companies.

From 1980 onwards, information on the basic research conducted by firms classified in nonmanufacturing has not been available. Therefore, the 1979 ratios of basic research expenditures as a proportion of total expenditures (0.0690 for federally financed expenditures and 0.0116 for privately financed expenditures) have been used for 1980 and each subsequent year.

Table 5. Industry-financed research and development expenditures,[1] current dollars, 1921-52

(In millions)

Year	Expenditures	Year	Expenditures
1921	$92	1937	$263
1922	99	1938	296
1923	107	1939	334
1924	115	1940	378
1925	124	1941	355
1926	133	1942	324
1927	143	1943	346
1928	158	1944	462
1929	175	1945	647
1930	193	1946	857
1931	214	1947	1,050
1932	187	1948	1,150
1933	163	1949	990
1934	184	1950	1,180
1935	207	1951	1,300
1936	233	1952	1,708

[1]Expenditures for basic plus applied research.

Source: N.E. Terleckyj, *R and D as a Source of Growth of Productivity and Income*, National Planning Association, Working Paper, May 18, 1982, table 1, p. 21.

Table 6. Federally financed research and development expenditures conducted in industry,[1] current dollars, 1938-52

(In millions)

Year	Expenditures	Year	Expenditures
1938	0	1946	$350
1939	$30	1947	520
1940	60	1948	670
1941	90	1949	800
1942	220	1950	800
1943	440	1951	1,000
1944	490	1952	1,100
1945	560		

[1]Expenditures for basic plus applied research.

Source: Blank and Stigler (1957, p. 14), based on Department of Defense sources. Figures for 1938-40 are assumed; all data are calculated as total research conducted in industry less funds raised by industry.

Table 7. Extrapolated values of the Jaffe-Griliches R&D deflator, 1921-57, and actual values, 1958-87

(Index, 1982 = 100)

Year	Deflator	Year	Deflator
Extrapolated values:		1955	24.62
1921	12.90	1956	25.58
1922	11.78	1957	26.54
1923	12.29	Actual values:	
1924	12.09	1958	27.50
1925	12.39	1959	28.22
1926	12.19	1960	28.91
1927	11.89	1961	29.33
1928	11.99	1962	30.01
1929	11.99	1963	30.40
1930	11.58	1964	31.22
1931	10.36	1965	31.87
1932	8.83	1966	33.08
1933	8.53	1967	34.35
1934	9.54	1968	36.32
1935	9.85	1969	38.22
1936	9.85	1970	40.32
1937	10.46	1971	42.66
1938	10.26	1972	44.58
1939	10.05	1973	47.20
1940	10.36	1974	51.85
1941	11.17	1975	57.45
1942	12.09	1976	61.55
1943	12.50	1977	65.79
1944	12.70	1978	70.71
1945	13.11	1979	76.98
1946	16.87	1980	85.07
1947	18.49	1981	93.73
1948	19.78	1982	100.00
1949	20.20	1983	103.11
1950	20.77	1984	106.42
1951	22.06	1985	109.42
1952	22.70	1986	112.62
1953	23.36	1987	115.42
1954	23.87		

Source: Calculated in tables D-1, D-2, and D-3 of appendix D and described in the text of that appendix. The deflators reported in appendix D are here converted to the base 1982 = 100.

Table 8. Implicit price deflator for GNP, 1921-87

(Index, 1982 = 100)

Year	Deflator	Year	Deflator	Year	Deflator
1921	15.5	1943	15.1	1965	33.8
1922	14.4	1944	15.3	1966	35.0
1923	14.9	1945	15.7	1967	35.9
1924	14.7	1946	19.4	1968	37.7
1925	15.0	1947	22.1	1969	39.8
1926	14.8	1948	23.6	1970	42.0
1927	14.5	1949	23.5	1971	44.4
1928	14.6	1950	23.9	1972	46.5
1929	14.6	1951	25.1	1973	49.5
1930	14.2	1952	25.5	1974	54.0
1931	13.0	1953	25.9	1975	59.3
1932	11.5	1954	26.3	1976	63.1
1933	11.2	1955	27.2	1977	67.3
1934	12.2	1956	28.1	1978	72.2
1935	12.5	1957	29.1	1979	78.6
1936	12.5	1958	29.7	1980	85.7
1937	13.1	1959	30.4	1981	94.0
1938	12.9	1960	30.9	1982	100.0
1939	12.7	1961	31.2	1983	103.9
1940	13.0	1962	31.9	1984	107.7
1941	13.8	1963	32.4	1985	111.2
1942	14.7	1964	32.9	1986	114.1
				1987	117.5

Sources: *Economic Report of the President*, February 1988, table B-3, p. 252, for 1983 to 1987; *National Income and Product Accounts, 1929-1982, Statistical Tables*, table 1.25, p. 87, for 1921 to 1928, and table 7.4, p. 327, for 1929 to 1982.

Appendix D uses these values of the GNP deflator to determine the estimates of the R&D deflator reported in table 7.

Table 9. Applied research and development expenditures, food and kindred products, SIC 20, current dollars, 1958-83

(In millions)

Year	Total	Federally financed	Industry financed
1958	$66	0	$66
1959	74	0	74
1960	92	0	92
1961	92	0	92
1962	98	0	98
1963	102	0	102
1964	118	0	118
1965	131	0	131
1966	130	0	130
1967	134	0	134
1968	165	0	165
1969	179	0	179
1970	206	0	206
1971	211	0	211
1972	227	0	227
1973	243	0	243
1974	283	0	283
1975	273	0	273
1976	308	0	308
1977[1]	348	0	348
1979	420	0	420
1981	492	0	492
1983	636	0	636

[1]Since 1977, the applied product field data have been collected every 2 years.

Sources: National Science Foundation, *National Patterns of Science and Technology Resources, 1986*, table 46; *Research and Development in Industry* for the following years: *1981*, table B-34; *1973*, table B-47, *1966*, table 81; also unpublished listings from Nestor Terleckyj.

Table 10. Constant-dollar gross investment in research and development, nonfarm business, 1948-87

(In billions of 1982 dollars)

Year	Applied research	Basic research
1948	$5.39	$0.43
1949	4.54	.36
1950	5.27	.42
1951	5.46	.43
1952	6.97	.55
1953	8.96	.65
1954	9.24	.70
1955	9.46	.78
1956	12.10	.97
1957	12.06	1.00
1958	12.42	1.06
1959	13.37	1.03
1960	14.44	1.18
1961	14.99	1.23
1962	15.76	1.31
1963	16.55	1.40
1964	17.47	1.39
1965	19.10	1.45
1966	20.61	1.54
1967	22.27	1.43
1968	23.32	1.47
1969	24.78	1.41
1970	24.59	1.31
1971	24.09	1.28
1972	25.00	1.26
1973	26.88	1.28
1974	27.44	1.26
1975	26.31	1.23
1976	27.50	1.25
1977	28.54	1.29
1978	30.39	1.36
1979	32.46	1.42
1980	34.85	1.49
1981	36.65	1.69
1982	38.28	1.81
1983	40.22	1.98
1984	43.83	2.27
1985	45.65	2.42
1986	46.82	2.50
1987	48.17	2.57

Note: Annual R&D expenditures in current dollars, as shown in tables 2 and 3, are converted to 1982 dollars using the Jaffe-Griliches deflator listed in table 7.

Table 11. The stock of research and development, nonfarm business, 1948-87

(In billions of 1982 dollars)

Year	Total	Applied research[1]	Basic research[2]
1948	$29.89	$26.63	$3.26
1949	32.76	29.23	3.53
1950	35.59	31.70	3.89
1951	37.33	33.07	4.26
1952	39.71	35.03	4.68
1953	42.09	36.99	5.10
1954	45.72	40.26	5.46
1955	51.07	45.19	5.87
1956	56.22	49.91	6.31
1957	61.24	54.38	6.86
1958	68.55	61.04	7.51
1959	75.21	66.99	8.22
1960	81.70	72.71	8.99
1961	88.78	78.82	9.96
1962	96.34	85.37	10.97
1963	103.85	91.82	12.03
1964	111.45	98.40	13.06
1965	119.35	105.11	14.24
1966	127.54	112.07	15.47
1967	136.74	119.96	16.78
1968	146.76	128.57	18.18
1969	157.56	137.99	19.57
1970	168.53	147.51	21.02
1971	180.10	157.54	22.56
1972	190.37	166.38	23.99
1973	199.29	173.82	25.46
1974	208.32	181.45	26.88
1975	218.37	190.18	28.19
1976	228.07	198.60	29.47
1977	235.79	205.05	30.73
1978	244.06	212.05	32.01
1979	252.65	219.39	33.27
1980	262.33	227.83	34.50
1981	273.26	237.51	35.75
1982	285.64	248.61	37.04
1983	298.80	260.40	38.40
1984	312.46	272.64	39.82
1985	326.91	285.60	41.31
1986	343.88	300.87	43.00
1987	361.25	316.43	44.82

[1]Based on a 2-year lag and 0.1 geometric depreciation.
[2]Based on a 5-year lag and zero depreciation.

Table 12. Rate of growth of the stock of research and development, 1948-87

(Average annual percent change)

Period	Total stock	Applied research[1]	Basic research[2]
1948-87	6.6	6.6	6.9
1948-73	7.9	7.8	8.6
1973-87	4.3	4.4	4.1

[1]Assumes a 2-year lag and 0.1 geometric depreciation.
[2]Assumes a 5-year lag and zero depreciation.

Table 13. Rate of depreciation, annual growth of the stock of research and development, and the implied research share, nonfarm business, 1948-87

Year[1]	Rate of depreciation (1)	Growth of research stock (2)	Assumed real return to a unit of research (3)	Implied research share (4)
1948-49	0.089	0.096	0.30	0.012
1950	.089	.086	.30	.012
1951	.089	.049	.30	.012
1952	.089	.064	.30	.012
1953	.088	.060	.30	.012
1954	.088	.086	.30	.013
1955	.088	.117	.30	.014
1956	.088	.101	.30	.015
1957	.089	.089	.30	.016
1958	.089	.119	.30	.017
1959	.089	.097	.30	.019
1960	.089	.086	.30	.020
1961	.089	.087	.30	.021
1962	.089	.085	.30	.022
1963	.089	.078	.30	.022
1964	.088	.073	.30	.023
1965	.088	.071	.30	.023
1966	.088	.069	.30	.023
1967	.088	.072	.30	.024
1968	.088	.073	.30	.025
1969	.088	.074	.30	.026
1970	.088	.070	.30	.027
1971	.088	.069	.30	.029
1972	.087	.057	.30	.029
1973	.087	.047	.30	.029
1974	.087	.045	.30	.030
1975	.087	.048	.30	.032
1976	.087	.044	.30	.033
1977	.087	.034	.30	.032
1978	.087	.035	.30	.031
1979	.087	.035	.30	.031
1980	.087	.038	.30	.032
1981	.087	.042	.30	.033
1982	.087	.045	.30	.035
1983	.087	.046	.30	.037
1984	.087	.046	.30	.036
1985	.087	.046	.30	.035
1986	.087	.052	.30	.036
1987	.087	.051	.30	.036

[1]The figures on the growth of the research stock listed in column (2) refer to year-to-year growth figures, as between 1948 and 1949 or 1984 and 1985. Research shares are calculated as the averages for the 2 years involved in any binary comparison. The 30-percent figure is used for both years in these calculations. Finally, the rate of depreciation expresses the percentage loss of the total research stock existing in the first year of each binary comparison.

Table 14. Annual contribution of research and development to productivity growth, nonfarm business, 1949-87

(In percent)

Year	Contribution	Year	Contribution
1949	0.11	1969	0.18
1950	.10	1970	.18
1951	.06	1971	.19
1952	.07	1972	.16
1953	.07	1973	.13
1954	.11	1974	.13
1955	.15	1975	.15
1956	.14	1976	.14
1957	.13	1977	.11
1958	.20	1978	.11
1959	.17	1979	.11
1960	.16		
1961	.17	1980	.12
1962	.18	1981	.14
1963	.17	1982	.16
1964	.16	1983	.16
1965	.16	1984	.16
1966	.15	1985	.16
1967	.17	1986	.18
1968	.18	1987	.18

Table 15. Long-term contribution of research and development to productivity growth, nonfarm business, 1947-87

(Average annual percent change)

Period	Contribution
1948-87	0.15
1948-73	.15
1973-87	.14

Table 16. Constant-dollar output, nonfarm business, 1948-87

(In billions of 1982 dollars)

Year	Output	Year	Output
1948	$824.9	1968	$1,757.1
1949	805.5	1969	1,804.3
1950	885.4	1970	1,784.6
1951	954.7	1971	1,832.8
1952	985.5	1972	1,952.3
1953	1,032.2	1973	2,073.9
1954	1,011.5	1974	2,034.7
1955	1,084.7	1975	1,986.0
1956	1,118.8	1976	2,107.7
1957	1,133.6	1977	2,232.9
1958	1,109.9	1978	2,366.4
1959	1,196.0	1979	2,410.0
1960	1,215.2	1980	2,379.9
1961	1,239.5	1981	2,421.1
1962	1,307.7	1982	2,340.9
1963	1,369.8	1983	2,458.6
1964	1,456.7	1984	2,664.0
1965	1,549.4	1985	2,768.4
1966	1,636.3	1986	2,865.2
1967	1,677.7	1987	2,973.7

Table 17. The stock of research and development, manufacturing and nonmanufacturing, 1948-87

(In billions of 1982 dollars)

Year	Manufacturing	Nonmanufacturing
1948	$29.45	$0.44
1949	32.28	.48
1950	35.06	.53
1951	36.78	.55
1952	39.12	.59
1953	41.47	.62
1954	45.05	.68
1955	50.31	.75
1956	55.39	.83
1957	60.33	.90
1958	67.53	1.01
1959	74.10	1.11
1960	80.50	1.21
1961	87.51	1.27
1962	94.99	1.35
1963	102.39	1.46
1964	109.85	1.60
1965	117.61	1.74
1966	125.66	1.87
1967	134.67	2.07
1968	144.49	2.27
1969	155.00	2.56
1970	165.73	2.80
1971	176.91	3.10
1972	186.98	3.39
1973	195.60	3.69
1974	204.34	3.98
1975	214.11	4.26
1976	223.62	4.46
1977	230.99	4.80
1978	238.92	5.13
1979	247.15	5.50
1980	256.32	6.01
1981	266.68	6.57
1982	278.46	7.19
1983	291.16	7.64
1984	304.43	8.03
1985	318.49	8.42
1986	334.96	8.92
1987	351.92	9.34

Table 18. Growth rate of the stock of research and development and its contribution to productivity growth, manufacturing and nonmanufacturing, 1948-87

Period	Manufacturing		Nonmanufacturing	
	Growth of the research stock	Contribution to productivity growth	Growth of the research stock	Contribution to productivity growth
1948-87	6.6	0.49	8.1	0.00
1948-73	7.9	.50	8.9	.00
1973-87	4.3	.49	6.9	.01

Chapter VI. Alternative Measures

The preferred measures of the R&D stock constructed and discussed in the previous chapter are based on a 2-year lag between applied research expenditures and their impact on productivity and a 5-year lag for basic research, 10 percent geometric depreciation for applied research, the Jaffe-Griliches deflator to deflate research expenditures, simple addition of basic plus applied research, a research expenditure series confined to privately financed research, and no change over time in the productivity impact of research.

This chapter relaxes many of these assumptions in turn and examines how such changes alter the growth of the research stock and the implied effect of R&D on productivity.

The preferred case, with all the assumptions outlined in chapter III, led to the central results presented in tables 12 and 15 of chapter V, which, for convenience, are repeated as panel A of table 19. These are the base-case results, and represent the standard against which all alternatives are evaluated. Panel A reports 1948-87, 1948-73, and 1973-87 rates of growth of the R&D stock and the influence these growth trends had on productivity growth in the nonfarm business sector. The table also reports the 1987 R&D stock, in 1982 dollars, again as a standard of reference for further comparisons.

Panels B and C of table 19 examine the impact of varying the lag before applied research takes effect. The main case in panel A assumes a 2-year lag between applied research expenditures and their impact on productivity. Panel B shows that if a 1-year lag is assumed instead, there is little effect on the growth of the research stock; the stock grows slightly less rapidly during 1948-87 and 1948-73 and slightly faster from 1973 to 1987. The change in the lag has no appreciable impact on productivity growth. In addition, the research stocks tend to be slightly greater in magnitude if a 1-year, rather than 2-year, delay is assumed before new research investment enters the stock.

Panel C examines a 3-year lag between applied research investment and its effect on productivity. The 3-year lag also does not essentially change the implied effect of R&D on productivity growth. The slightly faster growth of the research stock reported in panel C is not sufficient to generate any greater increase in productivity growth.

Panels D and E consider the impact of alternative methods of depreciation, which have a much more substantial effect on the rate of research growth and its influence on productivity. Panel D shows that, if there is no depreciation, research growth is substantially greater, with a 7.4-percent 1948-87 growth, in contrast to 6.6 percent in the preferred case. Research growth in each subperiod is also appreciably faster than in the main case. More importantly, the amount of the research stock is substantially greater if there is zero depreciation. The combination of faster research growth and a larger research stock causes R&D to have a much stronger influence on productivity growth than in the base case. The impact of R&D in 1948-87 is then 0.36 percent, in contrast to 0.15 percent in the base case. Furthermore, the research contribution increases from 0.32 in 1948-73 to 0.43 in 1973-87, as opposed to 0.15 and 0.14 under the baseline assumption. If research expenditures never depreciate, the research stock of course increases at a rapid rate which, if the rate of return is constant, contributes an ever greater amount to productivity growth.[1]

Panel E shows corresponding results if a more rapid rate of depreciation, 0.2 geometric depreciation, is assumed instead. In this variant, the growth of the research stock is slightly lower than in the main case, and the levels of the research stock are substantially lower than in the other cases. The combination of these influences means that the contribution of research and development to productivity is considerably smaller than in the other instances.

Panels F and G consider an alternative methodology in which the service price for the R&D stock includes a depreciation term as well as the assumed 30 percent rate of return. Clearly, calculations which assume zero depreciation, as in panel D, are unaffected by this alternative treatment. However, the main-case results of panel A, which assume 10 percent geometric depreciation, are altered if depreciation is treated differently.[2] If there is 10 percent depreciation plus a 0.30 net return to the research stock, so that the service price of the research stock is actually 0.40, panel F shows that the effect of

[1] Terleckyj (1982a) presented evidence suggesting that R&D investments do not depreciate. However, Griliches and Mairesse (1984) and Pakes and Schankerman (1984) conclude that R&D investments do depreciate.

[2] The alternative treatment of depreciation is examined in section 10 of appendix A.

Table 19. Effects of alternative assumptions on the growth of the stock of research and development and its contribution to multifactor productivity growth, nonfarm business, 1948-87

(Average annual percent change; 1987 stock in billions of 1982 dollars)

Period	Growth of the research stock	Contribution to productivity growth
	Panel A. Preferred estimates	
1948-87	6.6	0.15
1948-73	7.9	0.15
1973-87	4.3	0.14
	1987 stock = $361.25	
	Panel B. 1-year lag	
1948-87	6.5	0.15
1948-73	7.7	0.15
1973-87	4.4	0.15
	1987 stock = $376.43	
	Panel C. 3-year lag	
1948-87	6.7	0.14
1948-73	8.1	0.14
1973-87	4.3	0.14
	1987 stock = $345.69	
	Panel D. Zero depreciation	
1948-87	7.4	0.36
1948-73	8.4	0.32
1973-87	5.5	0.43
	1987 stock = $911.28	
	Panel E. 0.2 geometric depreciation	
1948-87	6.5	0.09
1948-73	7.8	0.10
1973-87	4.1	0.09
	1987 stock = $233.80	
	Panel F. 0.1 geometric depreciation with a 0.4 service price	
1948-87	6.6	0.20
1948-73	7.9	0.20
1973-87	4.3	0.19
	1987 stock = $361.25	
	Panel G. 0.2 geometric depreciation with a 0.5 service price	
1948-87	6.5	0.16
1948-73	7.8	0.16
1973-87	4.1	0.15
	1987 stock = $233.80	
	Panel H. The GNP deflator	
1948-87	7.1	0.14
1948-73	8.5	0.14
1973-87	4.6	0.15
	1987 stock = $352.21	
	Panel I. 0.2 of federally funded research conducted in industry is included in the research stock	
1948-87	6.6	0.16
1948-73	8.2	0.18
1973-87	3.8	0.14
	1987 stock = $399.62	
	Panel J. The productivity impact of R&D declines from 0.30 in 1967 to 0.167 in 1987	
1948-87	6.6	0.12
1948-73	7.9	0.13
1973-87	4.3	0.10
	1987 stock = $361.25	
	Panel K. The productivity contribution is based on a 30 percent return to money, rather than real, research expenditures	
1948-87	6.6	0.14
1948-73	7.9	0.13
1973-87	4.3	0.14
	1987 stock = $361.25	

R&D on productivity growth is then approximately 0.20 or 0.19 percent per year, in contrast to 0.15 or 0.14 percent in the preferred results.

Panel G of table 19 reexamines the results of panel E, with 0.2 geometric depreciation, with this alternative treatment of the R&D service price. Under the alternative methodology, the service price for R&D is 0.5, consisting of 0.2 from depreciation plus a return term of 0.3. With a service price of 0.5, the effect on productivity growth is 0.16 percent a year, in contrast to about 0.09 percent a year in panel E, with similar depreciation patterns but a service price of only 0.3. However, under either panel F or panel G, R&D still has no appreciable effect on the productivity slowdown.

Panel H reports corresponding results if the GNP deflator is used instead of the Jaffe-Griliches deflator. Since the GNP deflator increases less rapidly than the Jaffe-Griliches deflator, this assumption implies a faster growth of the research stock; however, the magnitudes involved have relatively little impact on productivity growth.

Panel I considers results if 20 percent of the federally funded research conducted in industry is counted within the relevant research stock.[3] The most notable result is that the growth rate of the research stock declines more sharply after 1973 than in the main case. The growth of the research stock slows from 8.2 percent in 1948-73 to 3.8 percent in 1973-87. In contrast, the growth rates for a stock consisting only of privately financed research are 7.9 percent in 1948-73 and 4.3 percent in 1973-87. So the observed slowdown in R&D growth is sharper when Federal funds are included both because implied 1947-73 growth is then more rapid and because the suggested 1973-87 growth is slower. However, even if 20 percent of federally financed research conducted in industry is included, the effect of R&D on the productivity slowdown is still relatively slight. Finally, the 1987 R&D stock is approximately 11 percent greater if one-fifth of the federally financed expenditures conducted in industry is included in the relevant investment series.

[3] The National Science Foundation publication *National Patterns of Science and Technology Resources* provides annual information on federally financed research conducted in industry from 1953 to 1985. Virtually all of these expenditures are applied R&D. For years prior to 1953, the 1953 proportion (1.33 percent basic research, 98.67 percent applied research) is assumed.

Panel J allows for a linear decline in the contribution of a unit of research from 0.30 in 1967 to 0.167 in 1987. Such a reduction in the rate of return lowers both the long-term (1948-87) productivity contribution of R&D and the 1973-87 impact. However, the contribution of R&D to productivity growth declines only slightly, from 0.13 percent in 1948-73 to 0.10 percent in 1973-87.

Finally, panel K shows the productivity effect of R&D determined through the same procedures, except that both the research stock and output are measured in current rather than constant dollars. Within this alternative framework, the impact on R&D is again substantially similar to the base case.

Overall, these alternatives show that in most instances the effect on productivity growth is quite robust with respect to changes in the central assumptions. The important situation in which this is not the case is the rate of depreciation. If research investments do not depreciate, as Terleckyj argues, then the direct effect of research on productivity growth over the entire 1948-87 period would be 0.36 percent, substantially greater than the 0.15 percent effect in the preferred case. In addition, if the research stock cumulates without depreciation, then research steadily exerts a more important influence on productivity, increasing from 0.32 percent in 1948-73 to 0.43 percent in 1973-87. In such a scenario, R&D would have an increasing positive impact on output growth and would tend to accelerate productivity growth and increase the magnitude of the slowdown that is left to be explained by other factors.

Chapter VII. Directions for Future Work

The R&D stocks presented here are likely to indicate the general order of magnitude of the R&D impact on productivity growth reasonably well. The preferred stocks are based on a number of specific assumptions. However, only the assumption concerning the rate of depreciation has a significant effect on the overall conclusions.

Among the major sectors, reliable estimates of the research stock have been constructed for nonfarm business as a whole. In addition, estimates of the research stock have been prepared for the manufacturing and nonmanufacturing sectors. However, these stocks are subject to a greater margin of error.

The main limitations of the estimates produced here are in the areas of depreciation and lags. In particular, the assumption concerning the rate of depreciation has a major influence on the implied role of R&D in productivity growth. Much further work is necessary on this topic.

As mentioned in chapter III, the issue of depreciation should be investigated with detailed micro data for individual firms; however, so far even highly detailed data have not been able to generate definite and robust estimates of the rate of depreciation. Lags can also be investigated in similar data, but this issue has much less impact on the implied importance of research.

There are several other directions in which further useful work can be conducted. One is extension of the present measures to two-digit industry detail in manufacturing. Terleckyj has already prepared much of the data required to construct R&D stocks at the two-digit level, and further work could proceed along similar lines.

Another important area which requires further effort is the construction of an R&D stock for the farm sector. Work being conducted by Evenson and Huffman will be helpful in this context. In addition, the indirect effect of research stocks is particularly important in agriculture, and considerable useful work can be conducted on developing measures of these indirect influences within the farm sector.

More generally, the indirect effect of research could also be determined for the other major sectors and for each two-digit industry in manufacturing. In addition, further work on the impact which R&D embodied in capital goods and in materials has on productivity growth would be useful. In this context, it would be helpful to include industries outside manufacturing, which typically depend on sectors within manufacturing for much of their new technology, in the sample of industries considered. The entire issue of the indirect effect of R&D is an extremely important topic which could have a major impact on estimates of the influence of R&D on the economy.

Finally, construction of an improved deflator for R&D investment is also an important priority. Mansfield, Romeo, and Switzer (1983), Mansfield (1985), and Griliches (1984) have made considerable progress in this direction.

In summary, much remains to be learned about the direct and indirect effects of R&D. This bulletin has examined the direct effects in several major economic sectors and has developed plausible magnitudes of the direct impact of research on productivity growth in the nonfarm business sector. The preferred estimates indicate that the direct impact of R&D contributes 0.1 to 0.2 percent annually to productivity growth and did not contribute appreciably to the productivity slowdown. However, even when discussion is limited only to the direct effect of research, the magnitudes involved are still subject to considerable uncertainty, largely because it is difficult to determine the true rate of depreciation.

Appendix A. The Theoretical Model

This appendix provides a detailed description of the theoretical model underlying the estimates of the impact of research and development presented in this bulletin. The description attempts to serve two purposes: first, to present a clear and complete statement of the methodology used, and second, to provide a thorough discussion of many technical issues.

The first four sections of this appendix describe the methodology. In an attempt to ensure readability, the discussion abstracts from several important issues which are essential to a full understanding of the methodology. The next six sections provide a detailed discussion of these issues.

The 10 issues are:

1. General methods of growth accounting.
2. Application of growth accounting to R&D: Constant or variable factor shares.
3. Application of growth accounting to R&D: The rate of return to research.
4. Application of growth accounting to R&D: Determining the contribution of R&D to productivity growth.
5. The assumption of constant returns to scale.
6. Double counting of research inputs.
7. Depreciation of the R&D stock.
8. Duplication of research investment.
9. Empirical estimates of the rate of return to the R&D stock.
10. The service price of the R&D capital stock.

1. General methods of growth accounting

The analysis conducted here assumes a production function of the form

$$V = C(t) \cdot f(K,L,R) \tag{1}$$

in which V is real value added, which is produced as a function of inputs of capital (K), labor (L), and research and development (R). C(t) is an index of those elements of technology unrelated to research and development, and shows how much value added or output is derived from any combination of inputs. C(t) is a Hicks-neutral or multiplicative factor, and is expressed as a function of time, t.

Equation (1) is often expressed in terms of growth rates as

$$\dot{V}/V = \dot{C}/C + \epsilon_1\, \dot{K}/K + \epsilon_2\, \dot{L}/L + \epsilon_3\, \dot{R}/R \tag{2}$$

in which each term indicates a growth rate. For example, $\dot{K}/K$ is approximately equivalent to $(K_2-K_1)/K_1$ or the capital stock in a second year less the capital stock in the first year, all divided by the capital stock in the initial year. As such, $\dot{K}/K$ indicates the rate of growth of the capital stock. Similarly, the other terms in equation (2) reflect the growth of output ($\dot{V}/V$), the growth of technology unrelated to R&D ($\dot{C}/C$), and the growth of labor and research inputs. The coefficients ϵ_1, ϵ_2, and ϵ_3 are the three output elasticities, which show the effect which a percentage increase in the growth of each input has on the percentage growth rate of output.

Growth accounting essentially measures each of these output elasticities by each factor's share of total income. If each of the elasticities in equation (2) is measured by its factor share, then each factor's contribution to output growth can be determined by multiplying its income share by its rate of growth.

As the discussion below illustrates, use of income shares as weights in this way reflects the central assumption that each factor input is paid exactly its marginal product.

To clarify the economic intuition underlying such calculations, consider the case in which the stock of a particular input, S, increases from S_{t-1} in year t-1 to S_t in year t. Assume further that the price of this input is s. Then, under the critical assumption that the price of an input also reflects its marginal product, the added amount of this input contributes an additional $s(S_t-S_{t-1})$ to output. Dividing this expression by pV, the value of output, this increment of output contributes $s(S_t-S_{t-1})/pV$ to the percentage growth rate of output.

This ratio may be multiplied and divided by S and, further, $\dot{S}$ may be substituted for (S_t-S_{t-1}). The resulting expression, $(sS/pV)(\dot{S}/S)$, the product of the factor share of S times its rate of growth, is equivalent to $s(S_t-S_{t-1})/pV$, which is exactly the contribution which S makes to the percentage growth rate of output.

Therefore, under the assumption that each factor input is paid its marginal product, equation (2) can be rewritten as

$$\dot{V}/V = \dot{C}/C + \alpha_k\, \dot{K}/K + \alpha_l\, \dot{L}/L + \alpha_r\, \dot{R}/R \tag{3}$$

in which α_k, α_l and α_r are the factor shares for capital, labor, and research.

Many issues have to be dealt with in any application of the general methods of growth accounting to R&D inputs. The following section considers whether the general expression given in equation (3) above should appropriately be approximated by a Cobb-Douglas function. Section 3 then examines how equation (3) can be modified to be expressed in terms of the rate of return to the research and development stock. Section 4 next discusses how the productivity contribution of research and development is determined.

2. Application of growth accounting to R&D: Constant or variable factor shares

Many of the more important studies of the effect of R&D on productivity growth, such as Griliches (1973), assume a Cobb-Douglas function, which implies that the factor shares for capital, labor, and research are each constant. The methodology underlying such studies typically rewrites equation (3) as

$$\dot{V}/V - \alpha_k \dot{K}/K - \alpha_l \dot{L}/L = \dot{C}/C + \alpha_r \dot{R}/R \qquad (4)$$

On the left-hand side, the increase in output less the contribution of increased capital and labor is frequently referred to as the rate of growth of multifactor productivity or $\dot{A}/A$.

Equation (4) can then be written in terms of multifactor productivity growth as:

$$\dot{A}/A = \dot{C}/C + \alpha_r \dot{R}/R \qquad (5)$$

which indicates that the rate of multifactor productivity growth is equal to the contribution of other forms of technology ($\dot{C}/C$) plus the contribution of R&D.

If the research share is constant, regressions of the form

$$\dot{A}/A = a + b\, \dot{R}/R \qquad (6)$$

provide a as an estimate of $\dot{C}/C$, the rate of external technological growth, and b as an estimate of α_r, the research share, and therefore the contribution of growth in R&D to growth in productivity. However, if the research share is not constant, as the succeeding text argues is likely to be the case, alternative procedures, such as those discussed in the next section, have to be relied upon instead to establish the contribution of R&D to productivity growth.

Instead of assuming a constant research share, the present study allows each factor share, including the R&D share, to vary freely over each year. This decision was reached for three reasons. First, the flexible share version is inherently more general. Second, permitting each factor share to vary freely within each year is consistent with the procedures adopted in a prior BLS analysis of multifactor productivity growth which concentrated on establishing the effect of capital inputs on productivity growth (U.S. Department of Labor, 1983). Third, the empirical results presented in table 13 in chapter V of this bulletin clearly demonstrate that the research share increased substantially over the post-World War II period in the nonfarm business economy. The assumption of variable factor shares establishes a framework within which it is possible to allow for this trend. The present bulletin is therefore based on equation (3) above, which permits each factor share to vary freely from year to year.

The following section describes an alternative method of determining the productivity contribution of R&D in which the real return to a unit of research, rather than the research share, is regarded as constant over time.

3. Application of growth accounting to R&D: The rate of return to research

Most recent analyses of the productivity contribution of R&D do not assume a constant research share and therefore do not determine the impact of R&D on productivity growth through the relationship given in equations (5) and (6). Recent work instead typically calculates the rate of return to research expenditures. This section explains how this rate of return is usually established.

In this approach, the research share in equation (5) is replaced by

$$\alpha_r = (p_r R)/pV \qquad (7)$$

in which p_r is the rental price of a unit of the R&D stock, R is the R&D stock, p is the price of output, and V is real output. Substituting equation (7) in equation (5) leads to

$$\dot{A}/A = \dot{C}/C + (p_r R)/(pV)\ (\dot{R}/R) \qquad (8)$$

which is equivalent to

$$\dot{A}/A = \dot{C}/C + (p_r/p)\ (\dot{R}/V) \qquad (9)$$

In equation (9), p_r expresses the monetary return to a unit of research capital, while p is the price of output. The ratio of these two terms, (p_r/p), therefore expresses the relationship between the monetary return to the research stock and the general price level or, in other words, the real return to the research stock. $\dot{R}$ in equation (9) indicates the increase in the real research stock. The product of the real return to the research stock multiplied by the increase in the research stock, $(p_r/p)\ \dot{R}$, therefore expresses the additional output attributable to the increase in the R&D stock. Dividing $(p_r/p)\ \dot{R}$ by V, real output, expresses the additional output due to R&D in terms of a percentage rate growth of output.

Regression analysis based upon equation (9) provides:

$$\dot{A}/A = a + b\,\dot{R}/V \qquad (10)$$

in which a is an estimate of $\dot{C}/C$ and b is an estimate of (p_r/p), the real return to a unit of research capital, and consequently also the amount which a unit of research contributes to productivity and output growth.

Although equation (10) is expressed in terms of the infinitesimal calculus, it can be implemented with annual data. For example, if b is 0.30 and $\dot{R}/V$—expressed as an annual increase in the research stock as a percentage of value added—is 0.005, then this amount of additional research contributes 0.0015 or 0.15 percent to multifactor productivity growth.

4. Application of growth accounting to R&D: Determining the overall contribution of R&D to productivity growth

The first three sections have described how the annual contribution of R&D to productivity growth can be calculated from annual growth rates of each of the variables involved. In practice, however, the calculations reported in this bulletin used a slightly more complex, but closely related, method of calculation. This section describes the procedures used.

The contribution of R&D to productivity growth between any two years, t and t-1, can be expressed alternatively from

$$X_t = \alpha_r(\log R_t - \log R_{t-1}) \qquad (11)$$

in which α_r is the mean of the research shares in the two years in question and R_t and R_{t-1} are the research stocks in these same two years.

$CONTR_t$, the specific contribution of R&D to productivity growth in year t, can then determined from

$$CONTR_t = \exp(X_t) - 1.0 \qquad (12)$$

Once the annual contribution of R&D to productivity growth, $CONTR_t$, is determined from equation (12) for each year of a long-term sequence, the average contribution of R&D to productivity growth over a long-term period can easily be calculated from these annual data. To understand the procedures used here at an intuitive level, recall that if a variable increases 5 percent in one year, 3 percent in a second, and 10 percent in a third, the average annual rate of growth of this variable over the 3 years can be calculated as the geometric mean of one plus these growth rates, less one, or as: $((1.05)(1.03)(1.10))^{1/3} - 1.0$.

In the same way, $CONTR_{LT}$, the average annual contribution of R&D over n years, can be calculated from the geometric mean of one plus each of the annual contributions of R&D, $CONTR_t$, less one, or as:

$$CONTR_{LT} = [\prod_{t=1}^{n} (1 + CONTR_t)]^{1/n} - 1.0 \qquad (13)$$

in which $\prod_{t=1}^{n}$ indicates the product of n terms, where each term is one plus each of the n annual growth contributions. The nth root is later taken, and one is subtracted to obtain the eventual result.

Determining the appropriate research share, α_r, is obviously a central matter in determining the annual and long-term productivity contributions of R&D through equations (11) through (13). In accordance with the fundamental methodology of growth accounting, the research share used in equation (11) is calculated as the average research share for the two years concerned in each year-to-year comparison.

Specifically, the research share for each year is calculated from equation (7)

$$\alpha_r = (p_r/p)\,(R/V)$$

Consistent with the evidence presented in chapter III, the real return to research, p_r/p, is assumed to be 0.30 for each year in the main analysis. Substituting this value for p_r/p, the average research share for any 2 years t and t-1 is therefore

$$\alpha_r = [.30\,(R/V)_{t-1} + .30\,(R/V)_t\,] / 2.0 \qquad (14)$$

This value of α_r is used together with the estimated R&D stocks in equations (11), (12) and (13) to determine the annual and long-term contributions of R&D to productivity growth.

5. The assumption of constant returns to scale

Most applications of growth accounting assume constant returns to scale, which implies that the different elasticities in a relationship such as equation (2) add up to one. The constant returns to scale framework is also consistent with the use of factor shares as elasticities, as in equation (3), since it is well known that, if each input factor is paid exactly its marginal product, total income payments will be equal to total production only if there are constant returns to scale.

However, the constant returns to scale interpretation of growth accounting is more difficult to maintain when R&D is treated as an additional input. The main complication is that there is substantial evidence that resources used in R&D contribute more to productivity growth than they are paid.[1] Consequently, if each factor of production is

[1] The literature mentioned in chapter II, particularly Mansfield et al. (1977), demonstrates that the social return to R&D is consistently greater than the private return. The tendency to increasing returns to R&D is part of the more general point that knowledge provides increasing returns to scale. Romer (1986) analyzes this issue.

increased by the same percentage, then total production will increase by more than this percentage due to the higher returns associated with research inputs. Under these circumstances, it is difficult to maintain the assumption of constant returns to scale, which has traditionally simplified the calculation and interpretation of growth accounting.

The total return to R&D can be viewed at many different levels of aggregation. In one context, the return to research for individual firms can be studied. In a broader context, research can be examined at the industry level, which allows for externalities gained by firms which benefit from research conducted by other firms in the industry (Jaffe, 1986; Bernstein and Nadiri, 1986). In a still broader framework, research can be analyzed within the total economy, which allows for externalities gained by producers in completely different industries from those in which research is conducted.

Even in the most narrowly circumscribed of these frameworks, at the level of the individual firm, there is evidence that the return to research is unusually high compared to that of other assets. In part, unusually high returns are likely to reflect the high risk premium required for investment in R&D (Mansfield et al., 1971). In addition, some forms of research may still be undergoing a process of social and cultural diffusion during which their true advantages are not yet fully appreciated (Griliches, 1986).

When the social externalities involved in studying research at the industry or economywide level are added to this picture, it becomes clear that it is difficult to maintain the assumption of constant returns to scale, despite its theoretical and empirical advantages, when R&D is included as an input in growth accounting. Nevertheless, throughout this bulletin, the analysis consistently adopts the assumption of constant returns to scale in order to remain within the framework within which growth accounting has generally been discussed.

6. Double counting of research inputs

In the sort of data typically available for productivity calculations in the United States, the capital, labor, and materials inputs used in R&D are generally already included in the inputs used to calculate multifactor productivity growth at the firm or industry level (or equivalently, in the capital and labor inputs used to determine multifactor productivity at the national level). Because resources used in research are included once as capital or labor inputs and once as research inputs, they are typically counted twice.

To illustrate the principles involved here, divide total capital into its production and research components, K_p and K_r, and labor into its production and research elements, L_p and L_r. Consequently

$$K = K_p + K_r \text{ and } L = L_p + L_r$$

Materials used in research are not considered here; their inclusion would not fundamentally alter the analysis. Resources devoted to research are then

$$R = F(K_r, L_r)$$

where the function is an appropriately weighted summation of the K_r and L_r inputs.

The research share is then

$$\alpha_r = \alpha_{kr} + \alpha_{lr}$$

The production shares of capital and labor are then correspondingly α_{kp} and α_{lp}.

In a more complete portrayal of the roles of capital, labor, and R&D in productivity growth, the relationship is

$$\dot{B}/B = \dot{V}/V - \alpha_{kp}\,\dot{K}_p/K_p - \alpha_{lp}\,\dot{L}_p/L_p - \alpha_r\,\dot{R}/R \quad (16a)$$

A more accurate measure of the contribution of research and development to the residual can then be determined from regressions based on equation (16a)

$$\dot{B}/B = a' + \alpha_r'\,\dot{R}/R \quad (16b)$$

either through the research share methodology of equation (5) or the rate of return to research methodology of equation (9).

However, in practice, the estimates typically used to estimate the role of research are based on the relationship

$$\dot{A}/A = \dot{V}/V - \alpha_k\,\dot{K}/K - \alpha_l\,\dot{L}/L - \alpha_r\,\dot{R}/R \quad (17a)$$

Residuals based on (17a) are typically used instead of those based on (16a). However, equation (17a) is inaccurate because the capital and labor used in research are subtracted once as a portion of capital and labor inputs and again for a second time as a component of research input. Instead of (16b), the residual from which the role of research is determined is in this case

$$\dot{A}/A = a + \alpha_r\,\dot{R}/R \quad (17b)$$

In equation (16a), since the share terms α_{kp} and α_{lp} include no research inputs, the term $\alpha_r\dot{R}/R$ captures the total return to research inputs. It follows that the regression coefficient α_r' in equation (16b) will tend to reflect the total return to research, including both the private return and the broader social return to research.

The preceding section argued that research inputs are likely to be paid less than their marginal products because of the need for a risk premium or for other reasons. Abstracting from these considerations for the moment, assume that research inputs are in fact paid exactly their marginal product. Under these circumstances, when the contribution of capital and labor used in research is removed an additional time from the multifactor productivity index in equation (17a), the private value of research, which is the compensation paid these factors, is already subtracted. Consequently, equation (17b) shows only the social component of benefits to research, which is the amount of the total return which remains after the private return has already been removed. In contrast, equation (16a) did not double count research inputs in constructing the relevant residual, and equation (16b) therefore provided an estimate of the total impact of research, including both the private and social returns.

As Griliches and Lichtenberg (1984b) have pointed out, one can expect that market forces will equalize the private rate of return to research in different industries. However, there is no mechanism that ensures that the social return to research will be equalized in different industries. Therefore, the type of coefficient observed from estimating the usual relationship (17a) can best be interpreted as the average social return to research.

7. Depreciation of the R&D stock

Over time, any given research investment depreciates in the sense that it becomes less able to contribute to output and productivity. Investments in general can become less productive either because they decay, and so are able to produce less in a tangible physical sense, or because they become obsolete. It is possible to think of some circumstances in which R&D investments decay, as, for example, a new pesticide towards which insects develop effective resistance, so that research conducted on this compound becomes ineffective. On the other hand, it seems clear that most of the reduction in the productive potential of research investments occurs because of obsolescence rather than because of decay.

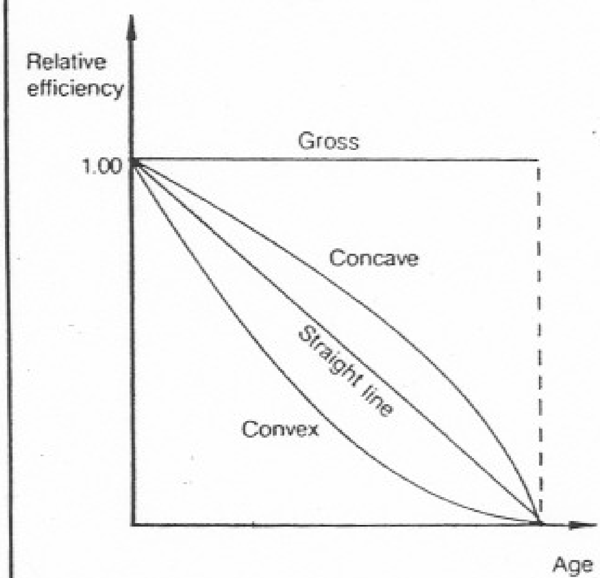
Two common examples can illustrate the nature of obsolescence in research investment. Probably the most frequent situation is one in which research conducted some years ago is displaced by more modern research investments conducted in later years which generate a superior product or process. A second example of obsolescence occurs if research which is effective under the specific economic circumstances for which it is designed is no longer economically relevant and becomes obsolete. For instance, research conducted on energy-intensive methods of production may be highly useful if oil prices are $8 or $10 per barrel, but may no longer be relevant if the price is $20 per barrel. These examples clearly illustrate the sense in which obsolescence is a central factor underlying the depreciation of R&D investments.

Understanding an asset's pattern of decay involves knowing the effective lifetime of the asset and selection of the appropriate rate of decay. In addition, it is necessary to know the correct time pattern of decay, such as geometric, hyperbolic, or one-hoss-shay.

Chart A-1, which is taken from the Bureau's prior work on multifactor productivity growth (U.S. Department of Labor, 1983), illustrates some of the main potential patterns of asset decay.

With gross stock or one-hoss-shay efficiency decline, the stock retains its full efficiency until the end of its productive life, and then suddenly disintegrates completely and is unable to contribute further to production. Another possibility is the straight-line function, in which losses from asset decay are equal in all time periods. With a concave function, as illustrated in chart A-1, asset efficiency declines slowly at first and then more rapidly. Conversely, with a convex function, losses from asset decay are great in the early years of an asset's life and smaller in later years. The Bureau chose a concave efficiency function for its measures of physical capital input.

Chart A-1.
General forms of an efficiency function



In the case of physical capital, the Bureau was able to utilize results from the highly detailed Hulten-Wykoff (1981) work on the rate and pattern of capital goods depreciation. Unfortunately, no work comparable in detail and scope to the Hulten-Wykoff study has ever been conducted on the depreciation of the R&D stock. Therefore, there is no conclusive or even reliable information on which to base the selection of the appropriate shape and speed of the depreciation of R&D investment.

Chapter III reviewed the available evidence on the depreciation of R&D spending and considered the assumptions made about depreciation in several leading studies. On the basis of this survey, the relatively simple geometric form of depreciation, in which the same percentage of the research stock depreciates each year, was chosen as the basic form of depreciation. (This pattern yields a convex efficiency function.) Ten percent geometric depreciation, in which 10 percent of the existing stock depreciates each year, was chosen as the central assumption. Zero percent and 20 percent geometric depreciation rates were chosen as alternative assumptions.

Choice of a specific rate of depreciation turns out to have important implications for the effect of R&D on productivity growth. Consequently, further empirical work on the pattern and rate of depreciation of the R&D stock would be very helpful.

8. Duplication of research investment

Much of research investment is duplicated in the sense that some firms duplicate research conducted by other firms, or perhaps invent around previous patents by developing slightly improved or somewhat different versions of existing products.

In addition, a good share of research spending probably goes towards gathering information already known, regenerating results once known, or perhaps systematizing and reordering prior results. Collection and intensive study of prior results are inevitably central to the process of developing new and improved understanding in any area.

Because of this duplication, R&D expenditures of $1 million do not necessarily create an R&D stock of $1 million. However, allowance for this duplication does not invalidate growth accounting estimates of the effect of R&D on productivity growth.

For example, if the true research stock is only half of what it appears to be, the actual rate of return to research is in fact twice what it might seem to be. The net effect of these offsetting changes in the magnitude of the research stock and its rate of return leaves the implied growth contribution of R&D unchanged. Nevertheless, it is clear that any estimate of the dollar magnitude of the R&D stock has to be interpreted with considerable caution.

9. Empirical estimates of the return to R&D

As indicated in section 3 above, estimates of the effect of R&D on productivity growth are now typically obtained from empirical estimates of the relationship given in equation (9), in which multifactor productivity growth is analyzed in terms of the increase in the research stock divided by output.

If the research stock does not depreciate, then the increase in the research stock is equal to current expenditures on research. However, if research does in fact depreciate, then the true increase in the research stock is smaller than observed research expenditures.

Early studies in the R&D literature dealt with relatively early years such as 1958, in which research spending was increasing rapidly (Griliches, 1973). These studies typically pointed out that when investment in any asset is increasing rapidly, depreciation tends to be slight relative to new observed expenditures, and observed current expenditures are a relatively good proxy for the true increase in the research stock.

However, research expenditures are a much less valid proxy during more recent years, in which the research stock has grown less rapidly. More recent work has typically also not emphasized the appropriate and necessary qualifications as strongly as earlier studies did.

If research investments depreciate, research expenditures will overstate the true increase in the research stock. Since the independent variable in equation (10) will then systematically be too large, the estimate of the regression coefficient or return to research may correspondingly be subject to substantial downward bias.[2]

However, this potential difficulty with many estimates of the return to research may not be serious. The Mansfield et al. (1977) estimates of the median return to individual research projects, which are based on careful study of the return to specific research projects rather than the regression methodology, which is potentially

[2] If R&D investments depreciate, the true return to research should be determined from regressions of the form

$$\dot{A}/A = a + b\,[RDEXP/V - \delta\, R/V] \qquad (a)$$

in which RDEXP is gross investment in research, δ is the rate of depreciation of the research stock, and R is the research stock. As before, $\dot{A}/A$ is the rate of multifactor productivity growth and V is output.

If the second component of the term in brackets is omitted, a typical example of omission of variables occurs. It is well established (Maddala (1977), page 156) that if the true regression is

$$Y = \beta_1 x_1 + \beta_2 x_2 \qquad (b)$$

and the regression estimated is instead

$$Y = b_1 x_1 \qquad (c)$$

the expected value of the coefficient b_1 in (c) will be

$$E(b_1) = \beta_1 + \beta_2\,(b_{12}) \qquad (d)$$

in which β_1 and β_2 are the true regression coefficients in (b) and b_{12} is the regression coefficient from

$$x_2 = a + b_{12}\, x_1 \qquad (e)$$

where the omitted variable is analyzed in terms of the included variable.

Applying these results to the bias which results from omitting the second portion of the independent variable in (a), and noting further that the productivity impact of both components of the independent variable in (a) should presumably be the same, so that $\beta_1 = \beta_2$ in the terminology of (b), then the expected value of estimates of the rate of return to R&D if depreciation is omitted will be

$$\beta_1 + \beta_1\,(b_{12}) \qquad (f)$$

where b_{12} is the regression coefficient from

$$-\,\delta R/V = a + b_{12}\, RDEXP/V \qquad (g)$$

If depreciation is approximately one-half of annual expenditures on research, b_{12} in (g) will be about -.5 and the estimate of the rate of return implied by (f), if the depreciation term is omitted, will be only about 0.5 β_1. Therefore, omission of the depreciation term may lead to substantial understatement in the rate of return to research.

subject to bias, suggest the rate of return is approximately 25 percent. This result is close to the 30 percent value chosen on the basis of a review of the regression evidence. The case study material therefore suggests the regression estimates are in fact not subject to serious bias.

In addition, section 10 below examines an alternative method of adjusting typical estimates of the rate of return to research for the potential impact of depreciation.

Most empirical estimates of the return to research have assumed that the rate of return is the same in all industries or firms. However, as Griliches and Lichtenberg (1984b) point out, the return to R&D in regressions such as equation (10) is typically a social rate of return. As mentioned in section 6 above, although one can expect the private return to research to be equalized across observations, there is no such presumption for the social rate of return. In addition, Clark and Griliches (1986) reported that the estimated social return to R&D can vary widely across industries, particularly depending on whether or not major technological changes had taken place in the industry in question. These results deserve careful further consideration.

10. The service price of the R&D capital stock

As Hall and Jorgenson (1967) have demonstrated, the service price per unit of capital can be expressed as

$$c = r + \delta \tag{18}$$

in which c is the service price per unit of capital, r is the rate of return, and δ is the rate of depreciation.

Some issues of notation and terminology have to be clarified here. First, equations (7), (8), and (9) above, which discussed the price of the R&D stock, used the term p_r to refer to the price or productivity contribution of a unit of the research stock. This concept is identical to c, the service price in the frequently adopted Hall-Jorgenson terminology; the notation c is used in equation (18) instead of p_r to ensure consistency with the Hall-Jorgenson notation, which has been widely adopted in the discussion of issues of productivity and taxation.

Second, the text above has often used the phrases "return" and "rate of return" to refer to the productivity contribution of an additional unit of the R&D stock. In the context of equation (18), this is equivalent to c, the service price. Jorgenson's concept of r, the internal rate of return after depreciation and taxes are paid, is different from the sense in which the phrase "rate of return" is used in the R&D literature. In the R&D context the term rate of return has consistently been used to describe the service price or, equivalently, productivity contribution.

Throughout almost all of the applications considered in this bulletin, therefore, the terms rate of return and return consistently refer to the service price. For example, the evidence that the rate of return to the research stock is on balance 30 percent implies that the service price or productivity contribution of a dollar of research is 30 cents.

In one section of this bulletin, the phrase rate of return instead refers to Jorgenson's internal rate of return characterized in equation (18). Panels F and G of table 19, which examine the effect of alternative assumptions, consider the change in empirical results which occurs if the 30 percent rate of return refers to r, the internal rate of return, rather than the service price in equation (18). Except for this single instance, however, all other discussion throughout this bulletin refers to c, the service price, by the terms rate of return or return.

Appendix B. Changes in the Rate of Return to Research and Development Over Time

Several studies have examined whether the rate of return to R&D declined over the 1970's. Griliches and Lichtenberg (1984a) examined data on productivity growth in a large number of manufacturing industries. Clark and Griliches (1984) studied data on divisions of major corporations, and Griliches (1986) examined firm-level data. Each of these studies found no evidence that the rate of return to R&D has declined over time. In contrast, Griliches (1980b) and Mansfield (1979) presented evidence that the rate of return to R&D has declined.

The work reported in this appendix considers the rate of return to R&D within three-digit manufacturing industries, which is similar to the industry-level analysis conducted by Griliches and Lichtenberg. In contrast to their work, however, the present study utilizes annual data on R&D intensity within each industry.

The initial task is to describe the data used in this discussion. The first fundamental series is R&D expenditures as a percentage of domestic shipments for each three-digit industry in each year from 1971 to 1980. The Bureau of the Census prepared these data in special tabulations for the Department of Labor's Bureau of International Labor Affairs. Several features of these data are important. The figures cover total research expenditures conducted in industry, including both privately and federally financed research. Data are collected at the company level and assigned to specific three-digit industries. All research conducted by each company, including work at both operating and central research establishments, is covered. Research conducted by both large and small companies is included.

There are several limitations to these data. The fact that they refer to companies rather than establishments is an important qualification. In addition, the data on research intensity are relatively unreliable for some industries in some years. Furthermore, as table 2 in chapter V shows, most of the slowdown in research spending in the 1970's consisted of federally financed funds, which are known to have a lesser impact on productivity growth than privately financed expenditures do. Since the research intensity considered here is total research, and since the privately financed proportion of total research increased over the decade, the shift in the research mix towards more productive types of research spending can be expected to have increased the overall return to total research. The data reliability and public/private composition issues are both considered further in the discussion below.

The second required data input is multifactor productivity growth in each industry in each year. These data are obtained from the National Bureau of Economic Research Program on Productivity Growth and Technical Change.[1]

The third variable is capacity utilization in each three-digit industry in each year. Data for 1973-80 are obtained from the Census Bureau series on capacity utilization. Capacity utilization in 1971 and 1972 is estimated on the basis of the Bureau of Economic Analysis two-digit figures on capacity utilization, which are similar in concept and trend to the Census series.

Following Clark-Griliches, the evidence is obtained from a regression in which annual multifactor productivity growth is the dependent variable and the independent variables are R&D intensity, the percentage change in capacity utilization, time, and an R&D and time interaction term. Empirical results are:

$$\begin{aligned}\dot{A}/A = {} & .0062 + \underset{(2.40)}{.281\ RD/S} + \underset{(5.96)}{.133\ \dot{CU}} \qquad n = 1287 \\ & \underset{(-2.22)}{-.0016\ t} \underset{(-.62)}{-.0135(RD/S)t} \\ & SEE = .055 \quad r^2 = .05\end{aligned}$$

in which $\dot{A}/A$ is annual multifactor productivity growth, RD/S is R&D as a percentage of shipments, $\dot{CU}$ is the percentage change in capacity utilization, t is time, and (RD/S) t is the R&D and time interaction. Research intensity, change in capacity utilization, and time are each significant and have the expected signs. However, as in Clark-Griliches, the R&D and time interaction term is not significantly different from zero, so there is no evidence that the rate of return to research declined in the 1970's.

Consequently, consideration of these additional data does not alter the overall impression that no substantial

[1] This is the series used in Griliches and Lichtenberg (1984b), and developed further by Gray (1987).

decline in the rate of return to research occurred in the 1970's. Overall, the evidence presented here supports Griliches and Lichtenberg (1984a), Clark and Griliches (1984), and Griliches (1986) in their conclusion that the rate of return to research did not decline in the 1970's.

There are two important qualifications to the evidence discussed here. First, the data on annual research intensity are less reliable in some industries than in others. Some data were missing in these industries and had to be estimated from the few years for which data were available.[2] However, if analysis is limited to the 109 of the 143 industries in which the research intensity data are available for the most years, evidence is generally comparable to that cited above. Specifically, the coefficient for the interaction term is -0.0219, with a t ratio of -1.04, which again provides no significant evidence of a decline in the rate of return to research.

Another potential issue is that the privately financed share of industrial research expenditures, which have a greater return, increased from 58 percent in 1971 to 68 percent in 1980 (National Science Foundation, 1984). Griliches (1986) estimated the increased return to privately financed expenditures from

$$R^* = R\,(1 + \delta\, s)$$

in which R^* is the increased true return due to the fact that there is a δ premium for a particular type of research which consists of some proportion, s, of total research. The Griliches estimates of δ were typically in the neighborhood of 0.10 or 0.15, which together with a 0.10 increase in s, the privately financed share of research, implies the overall return to research would have been expected to increase only slightly because of the increase in the privately financed proportion of research. The magnitudes involved are small. In addition, the share of basic R&D, which Griliches finds to have a much more substantial premium, decreased from 3.2 to 3.0 percent over this same period, which would conversely tend to lower the overall return to research.[3]

[2] Most of the missing observations are concentrated in industries such as textiles or apparel in which research intensity is quite low. Small changes in the research intensity of these industries are not likely to affect the estimated return to research greatly, since the estimated returns are dominated by the differences between highly research-intensive industries and the large number of less research-intensive industries.

[3] The stocks calculated in chapter V of this bulletin assume a 2-year lag between research expenditures and their impact on productivity growth. In contrast, the empirical analysis conducted here associates current productivity growth with current research expenditures. However, allowance for a 2- year lag is much less central to an interindustry analysis than to a time-series study because the interindustry pattern of research intensity is fairly stable across time. For example, if the rate of return to research is estimated from the interindustry sample for 7 individual years, first with no lag and second with a 2-year lag, the correlation between the two sets of estimated annual returns is 0.95.

Appendix C. Research and Development Expenditures in the Manufacturing and Nonmanufacturing Sectors

One important issue is whether reliable data on research can be obtained for the manufacturing sector and for nonmanufacturing, or whether the data reported have to be restricted to the nonfarm business sector, which includes both of these subsectors.

As discussed in chapter IV, the most relevant information on R&D on an industry basis is for research by product field. Unfortunately, the available tables on research by product field list only "other product fields, not elsewhere classified" in addition to the usual manufacturing fields. No SIC code is assigned to this category in the published tables, and therefore the residual category cannot readily be assigned to a specific product field in manufacturing or nonmanufacturing.

The sums involved in this residual category are quite large, consisting of $3 billion of a total of $29 billion applied research spending in 1977. Much of this spending is likely to be applied research in manufacturing fields which has not been assigned to a specific product field. Other spending is research in nonmanufacturing fields. However, no information is available on how much research falls into each category. Therefore, these data cannot be used to determine the exact amount of research taking place in manufacturing or nonmanufacturing product fields.

The central problem in developing a reliable measure of applied research in nonmanufacturing is determining how much research in "other product fields, not elsewhere classified" takes place in manufacturing and how much outside manufacturing. It would be preferable to obtain separate measures of the R&D stock in manufacturing and in nonmanufacturing, since the BLS treats these as separate major sectors. Therefore, considerable effort has been spent on this issue.

The best possible solution would be to examine the responses of individual firms to the National Science Foundation questionnaire and determine how much of research spending on the residual applied product field takes place in manufacturing product fields and how much in other areas. If feasible, this could be done for every 10 years or so, perhaps 1958, 1969, 1978, and 1981. Relatively few firms perform R&D, so the number of responses involved is manageable.

Because this is the only potentially decisive approach, BLS contacted the group at the Bureau of the Census which collects firm-level R&D data for the National Science Foundation. They were kind enough to examine the individual firm records within this residual product field for seven industries in the 1981 survey.[1]

Unfortunately, this preliminary examination indicated that this procedure would not provide usable data. Only 5 to 10 percent of firms reporting spending in this residual category gave detail on the types of research assigned to this classification. Therefore, the information provided in these data cannot be regarded as representative.

However, the examination did give some rough indication of the types of research classified into the residual category. These are shown in table C-1 for each of the seven industries. Examination of this information suggests that most of the research reported in this residual product field should appropriately be classified within a single product field in manufacturing. For example, research on metallurgy, listed under industrial chemicals, probably could appropriately be classified as occurring in the primary or fabricated metals applied field. Many of the other examples, such as asphalt roofing products under the petroleum category, also clearly belong in specific manufacturing product fields.

On the other hand, other examples refer to research conducted outside manufacturing applied product fields. For example, mineral extraction within the petroleum firms clearly refers to mining. Biotechnology could refer to agriculture or medicine as well as to manufacturing. In the aircraft and missiles category, flight safety presumably refers to transportation rather than to manufacturing, although this may be an intermediate case.

Computer software or systems development appears in several places on the list. It is uncertain whether this should properly appear as a separate product field outside manufacturing or as part of a manufacturing product field. According to William Starr of the Census, some firms report such computer work as a separate product field within the residual category and others report such

[1] The Bureau of Labor Statistics is grateful to Elinor Champion and William Starr of the Bureau of the Census for their help on this issue.

Table C-1. Examples of the research conducted in the residual category within each industry

Industrial chemicals	
	Metallurgical research
	Energy desalination
Petroleum	
	Asphalt roofing products
	Mineral extraction (an analysis of the relevant physics)
	Coal-alternative energy
	Biotechnology
	Energy conversion
Machinery	
	Printing
	Systems development
Electronic components	
	Railroad safety equipment
	Household appliances
	Solar collectors
	Hospital supplies
	Defense equipment
	Development of software and hardware prototypes
Automotive	
	Mechanical seal
	Small engine carburation
	Military avionics (computer software)
Aircraft and missiles	
	Air-conditioning application
	High-energy physics
	Noise control
	Flight safety
	Computer software
	Steam valves and traps
	Laser and electronics research
	Energy research
Optical, surgical, and photographic instruments	
	Dental products
	Optical instruments
	Batteries
	Photographic chemicals
	Clothing

work within their totals for specific applied fields within manufacturing.[2]

On the basis of this information, it is probably safe to conclude that most of the applied research assigned to the residual product field by manufacturing firms takes place in manufacturing. However, it is impossible to assign a definite percentage or determine how this ratio has changed over time. In addition, the reader should remember that, even though this is the only information available on this issue, the picture obtained is based on the relatively few firms which responded to this question.

Once it proved impossible to determine directly how much of the reported applied product field research took place in manufacturing and how much outside, it was necessary to search for other information relevant to this issue.

[2] According to National Science Foundation personnel, the Census Bureau conducted an analysis of how 100 firms responded to the R&D questionnaire in 1981. This showed that "computer systems" development accounted for the largest portion of R&D funds in the other product field category. Most firms were answering the product field question on an "end-product" rather than an intermediate product basis.

Another potential source of information is the industry (company-based) NSF data series. This indicates how much R&D, including basic and applied, is done by firms classified in nonmanufacturing industries. Data are available from 1958 on. The sums involved are much smaller, amounting to $830 million in 1977 in contrast to the $3 billion in the residual applied product field. The firms included in the company nonmanufacturing series do not include companies in the farm sector (although some private research, such as that conducted by seed firms, no doubt takes place in the farm sector).[3]

However, the fact that these data refer to nonmanufacturing companies, whereas the preferred industry measures utilize the applied product field concept, implies that these data are not really comparable.

The best data on fields in which research actually takes place are the 1974 estimates prepared by Scherer (1982a). These data are based on line of business (corporate division) information collected for the Federal Trade Commission. They are therefore subject to the qualification that the line of business classification is not necessarily the same as an applied product field classification, as is clear, for example, in the case of a private research laboratory which conducts tests on chemicals for an industrial firm such as Du Pont.[4]

Nevertheless, if it is tentatively assumed that the line of business data roughly approximate applied product fields, the Scherer data can provide a rough indication of the amount of research conducted outside manufacturing. According to the Scherer series, firms spent a total of $541.3 million in company-financed funds outside manufacturing in 1974.[5] Most of this ($413.2 million) was spent in the nonmanufacturing sector.

Most of the research conducted in the agriculture, mining, trade, finance, insurance, real estate, and transportation and public utilities lines of business is probably also conducted in the corresponding applied product fields. However, the $266.0 million spent in the construction and

[3] For example, according to table B-3 of the 1974 NSF *Research and Development in Industry* report, R&D conducted by nonmanufacturing companies includes firms classified in SIC 07-12, 14-17, 41-47, 49-67, 739, 807, and 891. These industries are all in nonfarm-nonmanufacturing. (Note that the definition of the farm sector used here, and in other BLS work on productivity growth, excludes agricultural services, SIC 07).

The 1987 *Standard Industrial Classification Manual* states that research farms, where presumably much of the research by seed firms is conducted, are classified as operating establishments in Agriculture, Forestry, and Fishing.

[4] Research and development and testing laboratories are classified in the Services major group. In 1987 they were classified in SIC 873.

[5] This amount is calculated as the sum of $128.1 million in agriculture; $60.3 million in mining; $39.7 million in trade, finance, insurance, and real estate; $47.2 million in transportation and public utilities; and $266.0 million in communications and services, including R&D services. Data are from table 2 of Scherer (1982a). Figure 1 of Scherer's study suggests considerably higher ($721 million) nonmanufacturing research spending because of a different treatment of petroleum extraction.

services industries includes expenditures in the R&D services industry. Part of this amount no doubt reflects work which research laboratories conduct in manufacturing fields for manufacturing firms, such as tests of potential carcinogens conducted for chemical firms.

Adding across the row assigned to construction and services in the Scherer matrix, approximately $40.6 million of R&D spending by construction and services industries are eventually assigned to manufacturing fields. However, this estimate is uncertain, since many of the items in this row cannot be published for disclosure reasons. In addition, an estimate of $40.6 million out of a total of $266 million research spending in construction and services seems a rather small share of expenditures in this category to attribute to manufacturing. This interpretation of the Scherer matrix probably understates the true amount of work conducted on manufacturing problems in research labs.

Nevertheless, if one subtracts this $40.6 million from the total $413.2 million nonfarm-nonmanufacturing research expenditures, these calculations suggest company-funded research in the nonfarm-nonmanufacturing sector was $372.6 million in 1974. In contrast, the company-based data, which also exclude the farm sector, suggest research spending outside manufacturing was $315 million in 1974. The relatively close correspondence between $315 million and $372.6 million suggests the company nonmanufacturing data may provide a relatively close approximation to actual research spending in nonmanufacturing lines of business.[6]

The assignment of particular research spending to the manufacturing sector is complicated further by the fact that all company spending for oil refining (SIC 29) and oil extraction (SIC 13) is combined in the available NSF data. Similarly, company spending for electrical equipment (SIC 36) and communications (SIC 48) is also mixed together. The latter limitation is especially important, since substantial expenditures for research, such as that performed by Bell Laboratories, take place on the borderline between these two industries. Furthermore, these same industry combinations are also mixed together within the applied product field data. The standard NSF publications imply that all spending in these areas occurs in manufacturing. The sums involved are quite large relative to total research spending in the nonfarm-nonmanufacturing sector; therefore, further work on dividing up these sums among the two industries concerned would be helpful.

It would be very difficult to attempt to apply similar techniques to other years to obtain estimates of time-series trends. The main problem is that the Scherer matrix exists only for 1974. In addition, the NSF data showing the amount which nonmanufacturing companies spent on other product fields, not elsewhere classified, extend back only to the mid-1960's.

In summary, the difficulties involved in creating a valid measure of the research stock over time in manufacturing and nonfarm-nonmanufacturing are not really manageable. Therefore, no extensive effort is made to calculate separate stocks for each of these sectors. Chapter V reports stocks for manufacturing and nonmanufacturing based on the company totals, without any adjustment. However, as the above discussion of the 1974 data makes clear, a stock based on such estimates is merely illustrative and cannot provide any substantial degree of reliability.

In a longer perspective, the only method of obtaining data which reliably split out the nonmanufacturing component is to ask firms to report exactly which items they include within the residual applied product field category in the NSF reports. Such information would have to be gathered in conjunction with the applied product field surveys.

No information is available on basic research expenditures by applied product field. All the NSF basic research data are collected at the company level, rather than by product field. Therefore, basic research has to be assigned to sectors or industries according to the industry classification of each company conducting research. In addition, the NSF tabulations for companies classified in nonmanufacturing SIC industries do not include firms in the farm sector. Therefore, all basic research conducted outside manufacturing is attributed to the nonfarm-nonmanufacturing sector.

[6] In addition, these calculations do not deal with how much research performed by manufacturing lines of business is conducted in nonmanufacturing areas. The Scherer matrix describes the eventual users of research performed in each line of business. However, it is unclear how much research manufacturers directly perform in other fields and how much is transferred in capital or materials sales.

Appendix D. Construction of the Jaffe-Griliches R&D Deflator

Construction of an appropriate deflator for R&D is one of the main problems which must be addressed in creating estimates of the R&D stock and determining its impact on productivity growth. This appendix describes all steps used to create the deflator used in chapter V. It describes the input series and intermediate steps used in these calculations.

The analysis starts with the Jaffe-Griliches suggestion, based on prior work by Jaffe, that the R&D deflator can be approximated by an index weighted 0.49 for the hourly compensation index and 0.51 for the implicit deflator, both for nonfinancial corporations (Griliches, 1984).

One of the advantages Griliches mentions for this index is that "it is based on data from a more relevant subsector of the economy." On this basis, the manufacturing series might be expected to provide a more relevant subsector, since almost all R&D spending takes place in manufacturing. However, since the Jaffe-Griliches measure based on data from nonfinancial corporations has received considerable attention in the R&D literature, and has proven to approximate more detailed R&D deflators rather well for years in which such a comparison has been feasible, the present discussion deals only with the preparation of measures of the Jaffe-Griliches index.

The stocks prepared in this bulletin include R&D investment which occurred between 1921 and 1987. However, data on nonfinancial corporations are available only from 1958 to 1987. Therefore, it is necessary to approximate the Jaffe-Griliches deflator between 1921 and 1957, so that all relevant research expenditures can be appropriately deflated.

A two-step procedure is used to estimate the Jaffe-Griliches deflator for years prior to 1958. First, the Jaffe-Griliches R&D deflator for 1947-57 is estimated on the basis of the 1958-87 relationship between data for the nonfinancial corporations and private nonfarm sectors.[1] Second, the Jaffe-Griliches deflator for 1921-46 is estimated on the basis of the 1947-87 relationship between the Jaffe-Griliches index for the nonfinancial corporations sector and the GNP deflator.

[1] As mentioned in chapter IV, the BLS major sector multifactor productivity measures all refer to the private nonfarm business sector, which excludes government enterprises. Therefore, all calculations throughout this bulletin also refer to the private nonfarm business sector.

Three comparisons were conducted for 1958-87. The first compared the index for hourly compensation in the nonfinancial corporations and nonfarm business sectors. The second compared the implicit output price deflator in these same two sectors. The third compared the Griliches index (0.49 times the compensation index plus 0.51 times the output price deflator) in the two sectors. Table D-1 presents all 1958-87 data for the nonfinancial corporations (NFC) and private nonfarm business (PNF) sectors. Regression results for the three comparisons were:

A. For hourly compensation:

$$\underset{(6.24)}{\text{NFC} = 2.2874} + \underset{(271.33)}{.9814\ \text{PNF}} \quad \text{t ratios}$$

$$r^2 = .9996 \qquad n = 30$$

$$\text{SEE} = 1.0050$$

The dependent variable, and therefore also the standard error of estimate, is measured in index values, with 1977= 100.

B. For the implicit price deflator:

$$\underset{(5.29)}{\text{NFC} = 2.7939} + \underset{(183.51)}{.9685\ \text{PNF}} \quad \text{t ratios}$$

$$r^2 = .9992 \qquad n = 30$$

$$\text{SEE} = 1.2424$$

C. For the Jaffe-Griliches index:

$$\underset{(5.83)}{\text{NFC} = 2.4991} + \underset{(228.79)}{.9752\ \text{PNF}} \quad \text{t ratios}$$

$$r^2 = .9995 \qquad n = 30$$

$$\text{SEE} = 1.0916$$

Equation C provides a reasonable fit in terms of the percentage of explained variance (r^2) and the standard

Table D-1. Indexes of the implicit price deflator for output, hourly compensation, and Jaffe-Griliches deflator, 1958-87

(Index, 1977 = 100)

Year	Nonfinancial corporations			Private nonfarm business sector		
	Implicit output price deflator	Hourly compensation	Jaffe-Griliches deflator	Implicit output price deflator	Hourly compensation	Jaffe-Griliches deflator
1958	49.2	34.1	41.8	47.0	32.2	39.7
1959	50.1	35.4	42.9	48.0	33.6	40.9
1960	50.7	36.9	43.9	48.8	35.0	42.0
1961	50.9	38.0	44.6	49.1	36.2	42.8
1962	51.5	39.5	45.6	50.0	37.7	44.0
1963	51.4	40.8	46.2	50.4	39.1	44.9
1964	52.1	42.6	47.4	51.0	40.9	46.1
1965	52.9	43.8	48.4	52.0	42.3	47.2
1966	54.2	46.2	50.3	53.7	44.8	49.3
1967	55.7	48.6	52.2	55.1	47.5	51.4
1968	58.2	52.1	55.2	57.6	51.1	54.4
1969	60.6	55.5	58.1	60.5	54.4	57.5
1970	63.3	59.2	61.3	63.4	58.1	60.8
1971	66.6	63.0	64.8	66.6	61.9	64.3
1972	68.9	66.6	67.8	68.9	66.1	67.5
1973	71.9	71.6	71.8	72.3	71.5	71.9
1974	79.4	78.2	78.8	79.7	77.9	78.8
1975	88.7	85.9	87.3	88.3	85.0	86.7
1976	94.2	92.9	93.6	93.7	92.5	93.1
1977	100.0	100.0	100.0	100.0	100.0	100.0
1978	106.6	108.4	107.5	107.0	109.0	108.0
1979	115.4	118.7	117.0	116.6	119.0	117.8
1980	127.6	131.1	129.3	128.1	130.5	129.3
1981	141.7	143.3	142.5	140.5	141.7	141.1
1982	149.8	154.3	152.0	149.4	152.2	150.8
1983	153.7	159.9	156.7	154.5	158.9	156.7
1984	157.9	165.8	161.8	158.9	165.9	162.3
1985	160.4	172.5	166.3	163.5	173.8	168.5
1986	163.2	179.5	171.2	167.5	181.7	174.5
1987	165.8	185.5	175.5	172.3	189.8	180.9

error of estimate, which refers to the explanation of the dependent variable, with an index value of 100.0 in the base year 1977. Therefore, no attempt was made to improve upon these estimates by separate further analyses of equations A and B. Equation C, which is a mixture of equations A and B, was chosen directly to predict the NFC values.

Consequently, 1947-57 values of the Jaffe-Griliches index, comparable to those available for the nonfinancial corporations sector in 1958-87, were predicted on the basis of regression equation C, and the 1947-57 values of the Jaffe-Griliches index in the private nonfarm business sector.[2] Table D-2 lists the implied 1947-57 values of the Jaffe-Griliches index.

[2] The actual value of the Jaffe-Griliches index in the nonfinancial corporations sector was 41.8 in 1958. Equation C, which is used to predict these values for 1947-57, predicts a 1958 value of 41.2. No attempt is made to chain these indexes in 1958.

A variety of other relationships between the NFC and PNF series were also examined, such as logarithmic or semi-logarithmic forms. In addition, a time trend was included as an additional variable in several analyses. However, the simple linear relationship reported here was regarded as the most reliable version for use in the extrapolation process involved in estimating the unknown data.

Once the deflators for 1947-57 are developed, the next task is to extend the corresponding deflator back to 1921. This was done by analyzing the 1947-87 relationship between the GNP deflator and all values of the Jaffe-Griliches index, including both the actual 1958-87 values in table D-1 and the estimated values for 1947-57 in table D-2. Results were:

$$\text{D. RD} = -4.3661 + 1.0412\ \text{GNP}$$
$$(-15.55) \qquad (325.50) \qquad \text{t ratios}$$

$$r^2 = .9996 \qquad n = 41$$

$$\text{SEE} = .9061$$

The GNP deflator predicts the R&D deflator fairly well, as measured by the closeness of the fit and the standard error of estimate. Note that the coefficient for the GNP deflator is considerably greater than one, indicating that the R&D deflator increases more rapidly than the GNP deflator over long periods of time.

The R&D deflator for 1921-46 was predicted from the GNP deflator in each of these years and regression

Table D-2. Indexes of the implicit price deflator for output and hourly compensation, private nonfarm business, and implied value of the Jaffe-Griliches deflator, nonfinancial corporations, 1947-57

(Index, 1977 = 100)

Year	Private nonfarm business sector			Extrapolated value of Jaffe-Griliches deflator in the NFC sector
	Implicit output price deflator	Hourly compensation	Jaffe-Griliches deflator	
1947	34.3	17.9	26.3	28.1
1948	36.8	19.4	28.3	30.1
1949	37.3	20.2	28.9	30.7
1950	37.9	21.4	29.8	31.6
1951	40.0	23.3	31.8	33.5
1952	40.7	24.6	32.8	34.5
1953	41.4	26.0	33.9	35.5
1954	42.0	27.0	34.7	36.3
1955	43.4	27.9	35.8	37.4
1956	44.9	29.4	37.3	38.9
1957	46.4	30.9	38.8	40.3

relationship D. Table D-3 shows annual values of the R&D deflator calculated in this way.[3]

What sort of implications do these alternative deflators have for measures of the R&D stock? We approach this issue by comparing the long-term growth of the research stock using the two deflators. The research stock for the nonfarm business sector grew at the following rates:

	Based upon Jaffe-Griliches deflator	*Based upon GNP deflator*	*Ratio*
1948-87	6.60	7.07	0.934
1948-73	7.88	8.48	.929
1973-87	4.34	4.60	.943

[3] Equation D predicts an index value of 29.8 in 1947, whereas table D-2 shows that the value of the Jaffe-Griliches index in the nonfinancial corporations sector predicted by equation C is 28.1. No attempt is made to chain these values in 1947.

If the 1921-46 index values were instead chained to the 28.1 value actually used for 1947, the price of research would be lower in 1921-46, which implies greater amounts of real research would have been conducted over this period. To illustrate the magnitudes involved, the 1948-87 growth of the research stock would then have been 6.4 percent, instead of 6.6 percent. Under these alternative calculations, the effect on productivity growth is 0.144 percent a year instead of the 0.145 percent a year which emerges from the main case. However, because of the nature of the rounding of these data, this slight change is sufficient to cause the impact of R&D to be 0.14 percent per year instead of 0.15 percent. However, the corresponding effect for 1958, mentioned in footnote 2, operates in an offsetting direction.

Table D-3. Extrapolated values of the Jaffe-Griliches research and development deflator, 1921-46

(Index, 1977 = 100)

Year	Deflator	Year	Deflator
1921	19.61	1934	14.51
1922	17.91	1935	14.97
1923	18.69	1936	14.97
1924	18.38	1937	15.90
1925	18.84	1938	15.59
1926	18.53	1939	15.28
1927	18.07	1940	15.75
1928	18.22	1941	16.98
1929	18.22	1942	18.38
1930	17.60	1943	19.00
1931	15.75	1944	19.31
1932	13.43	1945	19.92
1933	12.96	1946	25.65

Source: Calculated from the GNP deflator listed in table 8 in the main text, adjusted to 1977 = 100, and equation D above.

The growth rate of the research stock does not diverge radically under the two different deflators. In particular, 1973-87 research growth holds up fairly well when the Jaffe-Griliches deflator is used instead of the GNP deflator.

Finally, why does the alternative Jaffe-Griliches deflator still permit a substantial growth in real research spending here, while still another deflator constructed by Mansfield, Romeo, and Switzer (1983) showed only a relatively slow growth in real research expenditures? The main reason is that total expenditures on research as defined in the present bulletin increased from $10.010 billion in 1969 to $26.081 billion in 1979, reflecting the relatively rapid growth of privately financed research expenditures in industry, which accounts for the largest portion of the present measures. In contrast, Mansfield, Romeo, and Switzer report an increase from $7.39 billion in 1969 to $14.87 billion in 1979 in the specific industries they study. Their data show R&D expenditures increased 2.01 times from 1969 to 1979, whereas our data show research spending increased 2.61 times over the same period. Therefore, even when the relatively rapidly increasing Jaffe-Griliches deflator is used in the present context, instead of the GNP deflator, a substantial increase in real research investment still remains from 1969 to 1979.

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